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Arsenic in Plants Important to Two Yukon First Nations: Impacts of Gold Mining and Reclamation Practices

By Heather C. Nicholson

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Abstract

This project examines arsenic in plants growing near closed or reclaimed gold mines located in the traditional territories of two Yukon First Nations. A total of 238 soil and plant samples (comprising 9 different species) were collected from Mt. Nansen, Arctic Gold and Silver, and Venus Mine tailing properties. At each property, samples were collected near the suspected point source of contamination, approximately 1-3 km away, and from background sites. Species were chosen for their ethnobotanical significance to the Little Salmon/Carmacks and the Carcross/Tagish First Nations, based on interviews with Elders and other knowledgeable people. Total and inorganic arsenic concentrations were determined using ICP-MS and AAS instrumentation, and organic arsenic concentrations were calculated from the difference.

Uptake of arsenic by plants was low compared to soil arsenic concentrations. In both plants and soil, the arsenic form was predominantly inorganic. Concentrations in berries at all three sites were low or undetectable, and are therefore considered safe to eat under Health Canada tolerable daily intake guidelines for inorganic arsenic.

At Mt. Nansen, the lichen "caribou moss" (*Cetraria/Cladina* spp.), Bolete mushrooms (*Leccinum* spp.), and the medicinal shrubs willow (*Salix* spp.) and Labrador tea (*Ledum groenlandicum/L. decumbens* spp.) had high mean arsenic concentrations around point sources or at sites up to 1.5 km away. These localized high concentrations will not likely affect foraging animals, given their constant movement. However, Carmacks residents could avoid gathering all species with elevated arsenic around the Mt. Nansen mining property until reclamation is complete.

This report was reproduced, with minor changes, from a Master of Science Thesis completed by the author at the University of British Colombia, Department of Geography in December 2002

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Dedicated to the memory of

Howard Morton Brown

June 16, 1904 - December 28, 2000

Loving Grandfather, Mentor, and Environmentalist

Chapter 1: Introduction and Research Objectives

1.1 Introduction

This study examines arsenic in plants significant to Yukon's Little Salmon/Carmacks First Nation (LSCFN) and the Carcross/Tagish First Nation (CTFN), at three gold mine sites found within their respective traditional territories (Figure 1). Local residents who gather plant foods and medicines in the vicinity of the mines were concerned about arsenic exposure from direct consumption or from the foraging animals they hunt and trap.

Arsenic is commonly associated with gold-bearing ore. Prior to a completed mine reclamation program, arsenic can be released to the surrounding environment through windblown tailings, or through hydrologic pathways such as groundwater seepage and overland flow. The element can then enter plants by the root system or by foliar absorption. Health risks associated with ingesting plants containing arsenic depend on the concentration and the form of arsenic present; inorganic arsenic is more toxic than organic forms. It is, therefore, of interest to determine the forms taken up by different plants compared to surrounding soils, and in what concentrations.

Around the Mt. Nansen mining property, the LSCFN "pick blueberries, cranberries, blackberries, stone berries and arctic raspberries plus Labrador tea, caribou horn moss and other assorted medicinal plants. Mushrooms are also harvested in season" (Noble, 2000, 3). One component of the study was to determine if plants traditionally gathered near Mount Nansen by the LSCFN are safe to consume. Mining has intermittently taken place here since the 1920's. The most recent operation (BYG Natural Resources Inc: Oct '96 - Feb '99) closed due to environmental infractions. The site was left with an improperly designed tailings pond and an open pit as potential contamination sources. The Department of Indian Affairs and Northern Development (DIAND, also known as INAC) operate a wastewater treatment program that will likely continue until the mine is rehabilitated (P. Roach, pers. comm., 2002).

The CTFN gathered berries near two abandoned mines south of Carcross, Yukon, prior to warnings being raised about their high arsenic content. The tailings from the Venus and the Arctic Gold and Silver properties are now capped, and the sites are considered "contained" (B. Hartshorne, pers. comm., 2002). By using previously collected data from the tailing sites as well as collections made in 2001, pre- and post-reclamation arsenic concentrations could be compared, and health risks determined for the current levels of arsenic in the fruit.

1.2 Research Objectives

There were four primary objectives in this project:

- To determine if plants gathered in the vicinity of the three tailing sites are safe for consumption;
- To examine temporal and spatial trends of arsenic in soil and plants at three mine sites in varying stages of reclamation;
- To determine the form of arsenic preferentially taken up by different plant species;

- To investigate the ethnobotanical significance of common local plants to the First Nations.

The objectives of this study were initially identified by the Little Salmon/Carmacks First Nation in a proposal submitted in 2000 to the Yukon Local Contaminant Concerns (LCC) committee of the Northern Contaminants Program. The LCC Chair (Pat Roach) suggested that a comparison of reclaimed mine sites would be useful, and so the project was broadened to the Carcross region.

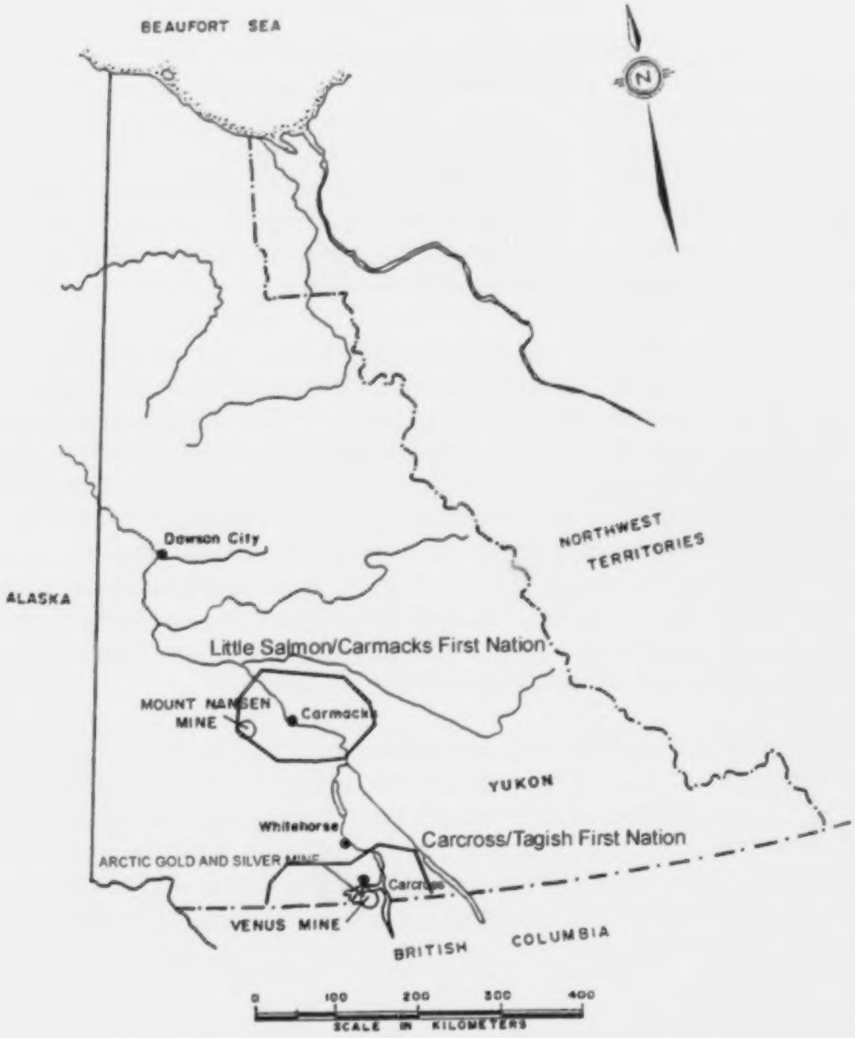

Figure 1. Location of the study sites within the traditional territories of the Little Salmon/Carmacks First Nation, and the Carcross/Tagish First Nation.

It is recognized that the original LSCFN proposal encompassed objectives other than testing for contamination in local vegetation:

> We would like to do more extensive testing and studies of plants, water and animals in that particular area to ensure the berries, plants and game [are] safe to continue to harvest… we are quite concerned with the effects on our health should we continue to harvest from the land in the area as we have done for thousands of years (Noble, 2000, 3).

Concluding statements from this study about the health of the land surrounding the Mount Nansen mine should be taken in context of the objectives, since an analysis of wildlife and water was beyond the scope of this study.

Chapter 2: Literature Review

2.1 Arsenic

2.1.1 Introduction

Arsenic is found naturally in water, air, soil, and biota, and is the 20th most abundant element in the earth's crust with a concentration of ~1.5 to 2 ppm (National Research Council, 1977). It is associated with zinc, lead, gold, copper, and particularly sulphide ores, and can be released through natural erosion and mining practices. Arsenic is itself mined and used for diverse agricultural and industrial applications. Its compounds have been used as insecticides, and for bronzing and medicinal purposes for millennia; bronze alloys have been dated back to 3000 B.C. (Nriagu and Azcue, 1990). Allegedly discovered by Albertus Magnus circa. 1250 A.D. as he mixed soap with orpiment, arsenic ("arsenicum" L. or "arsenikon" Gr. for yellow orpiment) gained notoriety in the Middle Ages as a murder and suicide poison. For the past two centuries, however, arsenic has been predominantly used for weed and insect control and as a wood preservative. High purity forms of the element have recently found roles in the manufacturing of lasers, ammunition, and pyrotechnics (Bhumbla and Keefer, 1994). Table 1 displays a list of some common arsenic compounds and their common industrial uses.

Often included in studies of heavy metals[1] because of its density of 5.72 g/cm^3 and toxic properties, arsenic is neither a metal nor non-metal as it displays properties of both. It is therefore commonly referred to as a semi-metal or metalloid. Arsenic occurs naturally in four oxidation states: As^{+5} (arsenate), As^{+3} (arsenite), As^{-3} (arsine), and As^0 (elemental arsenic). Along with environmental conditions (e.g. pH and soil type), the oxidation state determines the arsenic fraction that is mobile and available to biota. The toxicity of this element also depends on its form; inorganic arsenic is more phytotoxic than organoarsenicals (C-As structures). For example, the order of decreasing toxicity is: $As^{-3} > As^{+3} > As^{+5} >$ monomethylarsonic acid (MMA) > dimethylarsinic acid (DMA) (Pantsar-Kallio and Manninen, 1997). Because of the differing toxicities (leading to different health risks), and likely due to improved analytical techniques, there has been an increasing shift away from analyzing total arsenic over the past few decades.

2.1.2 Arsenic in Soil

Arsenic in soils comes from the weathering of rocks. The element is a component of more than 200 minerals, including arsenides and sulphides of silver, nickel and cobalt, plus oxides arsenates, and arsenites (Smedley and Kinniburgh, 2002). Some examples of minerals with arsenic are: adamite, annabergite, apatite, arsenopyrite (the most common), cobaltite, erythrite, glaucodot, mimetite, nickeline, olivenite, orpiment, proustite, realgar, scorodite, and skutterudite (Mottana *et al.*, 1977).
Arsenic in soils also comes from human inputs such as sewage, mining waste rock, insecticides, fertilizers, and atmospheric fallout of smelters and fossil fuel combustion.

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[1] This term is defined by the rather arbitrary physical property of density; elements exceeding 5 g/cm^3 are called *heavy metals*. Classifications based on biochemical properties would be more suitable.

Table 1. Common arsenicals and their historical uses (from Nriagu and Azcue, 1990, and supplemented by National Research Council, 1977; Lederer and Fensterheim, 1983; Koch, 1998). Dates indicate the first known use of the chemical.

Names and Abbreviations Inorganic Compounds	**Chemical Formula**	**Uses and other notes**
Arsenic metal, elemental arsenic: As^0	As	Alloy, solder, electrophotography
High-purity arsenic (99.9999%) e.g. Gallium arsenide	GaAs and other Group 3A and Group VA compounds	Photoemissive surfaces, optoelectric devices, solar cells, semiconductors
Arsenic acid (arsenate): As^5 or As (V)	$AsO(OH)_3$	1955: wood preservative salts, feed additive, cotton desiccant, defoliant
Arsenic sulphide		Pyrotechnics, depilatory (leather industry)
Arsenic trisulphide (orpiment)	As_2S_3	Pigment
Arsenic trioxide (white arsenic)	As_2O_3	Poison, soil sterilant, herbicide, medicine or virility compound in some past cultures
Arsenopyrite (mispickel)	FeAsS	Common sulphide mineral
Arsenous acid (arsenite): As^{+3} or As (III)	$As(OH)_3$	
Arsine (arsenic hydride) As^{-3} or As (-III)	AsH_3	Gas
Calcium arsenate	$Ca_3(AsO_4)_2$	1906: insecticide (cotton crops)
London purple	mixture of As_2O_3, $CaCO_3$, Fe and Al oxides, dye etc.	~1870-1960: insecticide (fruit crops)
Chromated copper arsenate (CCA)	Mixture of $CrAsO_4$ & $Cu_3(AsO_4)_2{*}4H_20$	1938: wood preservative
Copper arsenite (Scheele's green)	$Cu(AsO_2)_2$	Pigment
Lead arsenate	$Pb_3(AsO_4)_2$	1892: insecticide (esp. for gypsy moths)
Sodium arsenite	$NaAsO_2$	1890: soil sterilant, weed control, cattle/sheep dip, potato defoliant, tree debarker
Tetraarsenic tetrasulphide (realgar)	As_4S_4	Pigment; treatment of ulcers
Organic Compounds		
Arsanilic acid	$C_6H_4NH_2AsO(OH)_2$	Animal feed additive
Arsenobetaine: (AB)	$(CH_3)_3As^+ CH_2COO^-$	
Arsenocholine: (AC)	$(CH_3)_3As^+ CH_2CH_2OH$	
Arsenosugars: (X-XIII)	Composition varies depending on type of sugar	
Copper acetoarsenite (Paris green)	$Cu(CH_3COO)_2{*}3Cu(AsO_2)_2$	1868-1957: pigment, insecticide
Dimethylarsinic/cacodylic acid: (DMA)	$(CH_3)_2AsO(OH)$	Post WWII: defoliant (cotton fields)
Disodium methylarsonate: (DSMA)	$(CH_3)AsO(ONa)_2$	Post WWII: pesticide, herbicide
Lewisite (2-chlorovinyldichloroarsine)	$ClCH=CHAsCl_2$	WWI: Chemical warfare (gas)
Methylarsine ($MeAsH_2$)	CH_3AsH_2	
Monomethylarsonic acid: (MMA)	$CH_3AsO(OH)_2$	Post WWII: defoliant, herbicide
Salvarsan (arsphenamine)	Complicated	Treatment of syphilis & sleeping sickness

Table 2 quantifies the major anthropogenic sources of soil arsenic: emissions from waste commercial products (e.g. insecticides) and coal ash dominate.

Table 2. Global arsenic inputs to soil from human activities (from Nriagu and Azcue, 1990).

SOURCE	**As ($x10^6$)(kg/yr)**	
	Median	**Range**
Agricultural and food wastes	3	0-6.0
Animal wastes	2.8	1.2-4.4
Logging and other wood wastes	1.65	0-3
Urban refuse	0.4	0.09-0.7
Municipal sewage sludge	0.13	0.01-0.24
Miscellaneous organic wastes	0.13	0-0.25
Solid wastes, metal manufacturing	0.11	0.01-0.21
Coal fly ash and bottom ash	21.9	6.7-37
Fertilizer	0.01	0-0.02
Peat (agricultural and fuel uses)	0.27	0.04-0.5
Wastage of commercial products	38.5	36-41
Atmospheric fallout	13.2	8.4-18
Total input soils	**82**	**52-112**
Mine tailings	9.1	7.2-11
Smelter slags and wastes	6.8	4.5-9.0
Total discharge on land	**98**	**64-132**

The type of arsenic found naturally in soils is usually inorganic: typically arsenate, in its stable forms such as $HAsO_4^{2}$ and $H_2AsO_4^{-}$ (Wauchope, 1981; Burló *et al.*, 1999). Arsenite, as $As(OH)_3$, prevails under reducing conditions (Marin *et al.*, 1993) or if the soil is contaminated from smelting processes or mining activities prior to oxidizing back into arsenate (Porter and Peterson, 1977). Bacteria and fungi methylate convert both types of inorganic species into MMA and DMA, two organoarsenicals commonly found in soils.

The availability of soil arsenic to biota is determined by its concentration and chemical form, and by environmental conditions such as soil composition, soil pH and climate. Natural arsenic levels vary according to soil type but typical background concentrations range from <1 to 95 ppm: the range in soil type is represented by a mean of 4.4 ppm for podzols and a mean of 9.3 for histosols (Kabata-Pendias and Pendias, 2001). A literature review of studies that examined phytotoxic levels of soil arsenic showed arsenic concentrations were five times more phytotoxic in sands and loams, compared to clay soils (Sheppard, 1992). Soil type not only indicates the minerals present as potential binding sites, but also the relative clay and humus contents, which provide large surface areas with great capacities for cation exchange. Arsenate ions are fixed by many soil constituents such as clay, humus, and calcium (Kabata-Pendias and Pendias, 2001), but are most strongly bound to hydrous iron and aluminum ions that coat soil particles (Woolson, 1981). The resulting insoluble compounds are not easily leached out of the system by precipitation or irrigation. Due to its strong retention to surfaces, arsenic is not as mobile as other elements. In turn, these compounds may be re-oxidized, or further reduced into gaseous methyl arsines (Woolson, 1981). The composition of the parent rock material is a factor for the type of arsenic in soil. For example, soils formed from arsenopyrite rock can produce phytoavailable arsenic that is predominantly arsenite (Bech *et al.*, 1997).

If external arsenic concentrations increase, more arsenic is made available to plants (Paliouris and Hutchinson, 1991; Marin *et al.*, 1993). Like trace metals, arsenic concentrations can increase if the soil pH is lowered: acidic conditions enhance cation exchange and solubility, thereby mobilizing metals and metalloids. This was demonstrated with *Oryza sativa* (rice), when Marin *et al.* (1993) found that lowering the pH increased the amount of soluble arsenic available for uptake. Similarly, Meharg and Macnair (1991) found that as the pH increased, the rate of arsenate uptake decreased in *Holcus lanatus* (velvet grass). Bech *et al.* (1997) performed a case study of arsenic in vegetation growing around a Peruvian copper mine. Results showed how low clay content and acidified soil increased arsenic availability, the latter due to increased solubility of the iron and aluminum oxide binding compounds. Bioavailable arsenic can also increase when the pH is increased however, as sorption to iron oxides and particulate matter becomes weaker. For instance, when the pH is raised to >8.5 in semi-arid or arid environments, arsenic in sediments can experience high dissolution rates (Smedley and Kinniburgh, 2002).

2.1.3 Arsenic Uptake in Plants

Uptake of arsenic through the leaves can occur, particularly when herbicides and pesticides are sprayed directly on the plants. However, uptake is typically through the root-soil interface, driven by the water potential gradient between the air and the root system. Ions, including soluble arsenic species, move apoplastically with the influx of water through the root hairs to the cortex. The ions are barricaded from entering the stele and are instead "forced" into the protoplasm, where they are transferred to vessels via the pericycle (Punz and Sieghardt, 1993). Once in the vessels, they can be transported throughout the shoot. To overcome the plasma membrane barrier, specific protein carriers are responsible for shuttling ions across and into the cell. Arsenate shares a carrier with its chemical analogue, phosphate.

Arsenic uptake is generally low, and studies demonstrate that most plants have far lower total arsenic values than the medium in which they are growing (Milton and Johnson, 1999; Pitten *et al.*, 1999). Pitten *et al.* (1999) looked at an old military site where even though certain 'hot spots' yielded 250 g of arsenic in 1 kg soil (250 000 ppm), analysis of on-site *Holcus lanatus* showed its highest concentration was 26 mg/kg (ppm), and the median value was 0.7 mg/kg (ppm). Arsenic loads in terrestrial plants growing on uncontaminated sites typically do not exceed 0.2 ppm (Cullen and Reimer, 1989). In terms of arsenic speciation, Tamaki and Frankenberger (1992) found that arsenate was three to four times more likely to be absorbed by most terrestrial plants compared to arsenite. The type of plant, and mobility of the individual arsenic species are factors influencing where the arsenic is stored and how much can be absorbed.

As roots are the primary entry pathways, their arsenic concentrations are often higher than in other parts of the plant such as the stems, leaves, or fruits (Paliouris and

Hutchinson, 1991; Marin *et al.*, 1993; Dushenko *et al.*, 1995; Pitten *et al.*, 1999). However, trace elements, including arsenic, often accumulate in the extremities of a plant such as in twig ends, outer bark, and the tops of trees (Dunn, 1995).

2.1.4 Physiological and Biochemical Effects of Arsenic in Plants

The primary impact of arsenic toxicity on plants is a reduction in growth (Kabata-Pendias and Pendias, 2001). This response was noted with soil arsenic concentrations >2 ppm (Pitten *et al.*, 1999). Other responses include chlorosis, discolouration, necrosis, dehydration, and reduced availability of essential elements (National Research Council, 1977; Dushenko *et al.*, 1995). The latter study found that at high arsenic concentrations, the freshwater emergent plant *Typha latifolia* (cattails) showed leaf tip necrosis, reduced stand height, and decreased levels of copper, manganese and zinc in the root.

The thorough review by Punz and Sieghardt (1993) outlined the following important responses of plant roots to heavy metals, which can be applied to arsenic:

- changes in root biomass - typically a reduction in weight;
- changes in the root system architecture - increased lateral root growth leading to a compacted system;
- changes in growth rate;
- inhibition of root elongation - largely due to a disruption of cell division and mitosis.

They also noted other important morphological changes, including root discolouration, decreased root hair density, vessel diameter, and vessel number, and structural changes to hypodermis, endodermis, and pericycle. Further physiological responses include damage to root cell membrane, decreased water permeability of the plasmalemma, decreased turgor or plasmolysis, reduced root respiration, reduced water uptake, and increased water flow resistance (Punz and Seighardt, 1993).

Due to their chemical similarity, arsenate can replace phosphate in cellular processes such as transport, and enzyme reactions (e.g. arsenate inhibits pyruvate dehydrogenase, the enzyme involved in respiration). Arsenate uncouples oxidative phosphorylation by replacing stable phosphate esters used in creating ATP with unstable arsenate esters, thereby reducing the availability of phosphate for ATP production (Tamás and Wysocki, 2001).

Arsenate can reduce to arsenite, which then attacks protein sulfhydryls (Ullrich-Eberius *et al.*, 1989); reacting with thiol groups on the active site of enzymes, thereby inhibiting enzyme activity (Burló *et al.*, 1999; Tamás and Wysocki, 2001). Arsenite also disrupts root functions, inhibits leaves from taking up other elements, and at high enough concentrations, will inhibit seed germination (Carbonell *et al.*, 1998). Roots become increasing stunted and browned as concentrations are raised (Marcus-Wyner and Rains, 1982). Arsenite also inhibits pyruvate dehydrogenase (Koch, 1998) and can initiate lipid peroxidation (Sneller *et al.*, 2000). Rice plants, which predominantly take up the more toxic arsenite species due to the reducing conditions of their flooded habitats, exhibit "rice blight" or straighthead disease, which deforms panicles and florets, and affects sterility (Marin *et al.*, 1992).

The two organic arsenicals MMA and DMA may affect protein synthesis and water relations. Applications of DMA to cotton grass, rice, and tomato plants revealed several or all of the following conditions: root plasmolysis, leaf wilting, discolouration, curled leaf margins, and necrosis of leaf tips and margins (Marcus-Wyner and Rains, 1982; Marin *et al.*, 1992; Burló *et al.*, 1999). Absorption of other elements is also impacted: increased organic arsenic treatments on a wetland grass showed high sodium, and low potassium and magnesium concentrations in the root, and high calcium in the leaves (Carbonell *et al.*, 1998).

2.1.5 Plant Mechanisms to Reduce Toxicity

Plants utilize different avoidance and tolerance strategies to reduce arsenic toxicity. These strategies involve restricting the movement of the element into the plant, or by using a number of internal processes to detoxify the compound. Table 3 summarizes these strategies as described by Punz and Sieghardt (1993).

Table 3. Strategies by plants to avoid metal stress (from Punz and Sieghardt, 1993).

Resistance Strategy	**Classification of Response**
Exclusion of metal ions	Avoidance
Biochemical/enzymatic changes on the root surface	Avoidance
Extracellular deposition	Avoidance
Binding (fixation) to cell wall components	Avoidance
Binding to peptides (metallothioneins)	Tolerance
Binding to peptides (phytochelatins)	Tolerance
Compartmentalization in the vacuole	Tolerance
Excretion	Avoidance
Shedding of plant parts or whole organs	avoidance/tolerance

Plants appear to be selectively tolerant to different arsenic species. Since arsenite disturbs enzymes by reacting with thiols, more plants have evolved tolerance capabilities to arsenate. Arsenate tolerance is not limited to vascular plants however, and has been found in fungi and bacteria, as well as mosses, and lichens (Meharg and Macnair, 1990). Intolerant plants indiscriminately take up phosphate and arsenate together (Paliouris and Hutchinson, 1991), while "tolerant"[2] plants show reduced arsenate (Meharg and Macnair, 1990). General responses employed by arsenate-resistant plants to high concentrations include downregulation of phosphate/arsenate transport carriers leading to reduced uptake (Meharg and Macnair, 1990; Sharples *et al.*, 2000), phytochelation, conversion of arsenate into less toxic methylated species (Benson *et al.*, 1981; Meharg and Macnair, 1991), and the uninhibited extraction of soil arsenic by hyperaccumulators.

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[2] Terminology as used in the literature; it is recognized that reduced arsenate uptake in "tolerant" plants is in fact, an avoidance mechanism.

Phytochelatins are metal binding polypeptides that act as metal and semi-metal regulators, sequestering agents, and detoxifiers in plants (and some fungi), which function analogously to metallothioneins found in fungi, invertebrates, mammals and insects. Arsenic (both arsenate and arsenite forms) is one of the elements that will induce synthesis of phytochelatins (but not necessarily metallothioneins) (Grill *et al.*, 1987). Induction was observed *in vivo* and *in vitro* for *Rauvolfia serpentina* (snakeroot), *Arabidopsis* (thale cress), and *Silene vulgaris* (Schmöger *et al.*, 2000). Steffens (1990) suggests that phytochelatins may be part of a cytoplasm_vacuole shuttle system. The role of vacuole storage for phytochelatin-bound metals appears to be a relatively new subject of study and no information specific to arsenicals was found.

Hyperaccumulators are a special class of plants that tolerate high concentrations of metals normally toxic to "regular plants". Recently, *Pteris vittata* (brake fern) was discovered to be an accumulator of arsenic, containing 125 times the amount found in the soil, and converting much of the arsenate into arsenite as it translocated from the roots to the fronds (Ma *et al.*, 2001). This is the first known arsenic hyperaccumulator, and its potential use for cleaning up contaminated sites in suitable habitats is enormous.

Arsenic appears to accumulate in older tissues of some plants (Bech *et al.*, 1997), especially older leaves (Porter and Peterson, 1975; Wyttenbach *et al.*, 1996). These sinks allow the ions to be removed from sites where more damage could occur, and/or permit shedding to occur. Certainly litter exhibits accumulation (Milton and Johnson, 1999), though the authors recognize this could be due to surface contamination, binding by humus complexes, metabolism and subsequent excretion by bacteria, or as a plant detoxification mechanism such as leaf abscission. Marcus-Wyner and Rains (1982) observed a decrease in cotton leaf arsenic over 7 weeks from the day when the plants were sprayed with DMA. They suggested this was because the damaged leaves fell off, or the element was not being translocated into healthier tissues, or there was a dilution-effect as plant growth continued but the total arsenic content remained unchanged. Leaf abscission as a detoxification mechanism was more clearly demonstrated by a study of arsenic in different needle age classes of Norway spruce (Wyttenbach *et al.*, 1996). The resulting positive relationship between age and arsenic concentration was thought to be a result of the binding of the As^{3-} anion to mercapto groups of structural proteins in the leaf, and subsequent inability to translocate to younger needles.

Other recent data have shown that concentrations in leaves of deciduous trees are similar to or exceed concentrations in twigs, while coniferous needle concentrations tend to be lower (Dunn, 1995). This response was not observed with another conifer species; arsenic concentrations in *Pseudotsuga menziesii* (Douglas fir) were less in older needles, and highest in stem tissue (Warren *et al.*, 1968).

2.1.6 The Uptake of Arsenic by Humans

Arsenic enters the human body on a daily basis from various environmental media. The major pathways are via food and water ingestion, and inhalation (e.g. by smokers, or workers utilizing the element). Absorption through the skin can also occur, though this is uncommon. Seafood, mushrooms and other foods generally contain organic arsenic, while water usually contains inorganic arsenic. Not all the arsenic in foods is biologically available. According to the Canadian Council of Ministers of the Environment (CCME) most arsenic in fish is tied up in complex organic forms (e.g. arsenobetaine) that are not broken down in the human body, while the remainder are largely simple structures (e.g. trimethyl arsine) that are rapidly excreted (CCME, 2001).

Table 4 shows the average amount of inorganic arsenic taken in by Canadians, broken down by age groups and arsenic source. These are estimates only, based on data in previous studies, and assuming characteristics about a particular age group. For example, on a daily basis adults are assumed to breathe 23 m^3 of air, drink 1.5 L of water, and ingest 20 mg of soil, and smoking is based on the assumption of smoking 20 cigarettes per day with 40-120 ng of arsenic each (CCME, 1995).

The Agency for Toxic Substances and Disease Registry estimates that people who smoke two packs of cigarettes a day are inhaling 12 mg of arsenic per day (ATSDR, 1993). For a 70 kg adult, this is 85 times the value provided by Health Canada as a tolerable daily level of arsenic (section 2.1.9), excluding contributions from other sources shown in Table 4.

Table 4. Estimated average daily intake of inorganic arsenic by the Canadian general population (from CCME, 1995; adapted from Hughes *et al.*, 1994).

Age	**Assumed Body Weight (kg)**	**Estimated Daily Intake (µg/kg bw/day)**					
		Water	Food	Air	Soil/Dirt	**Total**	Cigarette smoking
0 to <6 months	7	0.5	0.2	0.0003	0.029	**0.729**	
6 months to <5 years	13	0.3	0.3	0.0004	0.062	**0.662**	
5 to <12 years	27	0.2	0.2	0.0004	0.007	**0.407**	
12 to <20 years	57	0.1	0.1	0.0004	0.004	**0.204**	0.01-0.04
20 – 70 years	70	0.1	0.08	0.0003	0.003	**0.183**	0.01-0.03

2.1.7 The Movement of Arsenic in the Body

From the digestive tract or lungs, arsenic is rapidly absorbed into the bloodstream. Dissolved arsenic is more efficiently absorbed than low solubility compounds such as lead arsenate and gallium arsenide (National Research Council, 1999). Arsenic is bound to sulfhydryl-containing proteins or other compounds in the blood such as haemoglobin, glutathione, and cysteine, and then rapidly transported to organs such as the liver, spleen, kidney, lungs, and skin (Wickstroem, 1972). Due to the strong binding of arsenite to sulfhydryl groups (section 2.1.4), this form is more likely to accumulate in tissues compared to arsenate or organic arsenic, which are absorbed and then tend to be excreted (Bertolero *et al.*, 1987). As with plants, organic arsenic is considered much less toxic than inorganic arsenic.

According to the Federal-Provincial Subcommittee on Drinking Water (FPSDW), arsenic is most often stored in the skin, bone, and muscle (FPSDW, 1996). However, arsenic residence time is highest in the hair, nails, skin, and lungs, likely due to their strong presence of keratin (cysteine) or proteins (sulfhydryl groups) as binding sites (National Research Council, 1999).

The body uses two major ways to remove inorganic arsenic: methylation, and direct urinary excretion of the unaltered compound. In the former, the body can detoxify ~40-80% of ingested arsenite and arsenate by converting these inorganic forms into methylated organic forms, which are then largely excreted through urine, or to a lesser extent, eliminated through hair, nails, skin, breast milk, sweat, and faeces (FPSDW, 1996; National Research Council, 1999).

2.1.8 Effects of Arsenic in Humans

Arsenic was one of the 44 chemicals registered on Canada's first Priority Substances List in 1989, and assessed by 1994 under the Canadian Environmental Protection Act. Arsenic is considered a group 1 ("carcinogenic to humans") substance by Health Canada. Due to its carcinogenic properties, many arsenic-containing products have now been banned, including the insecticides that were so prevalent in past agricultural programs.

Organ systems affected by inorganic arsenic include the skin, respiratory, cardiovascular, immune, genitourinary, reproductive, gastrointestinal, and the nervous system. Some non-carcinogenic effects associated with arsenic exposure from drinking water include diabetes, skin thickening, tingling or numbness in limbs, hearing impairment, hypertension, anaemia, peripheral vascular (blackfoot) disease, and chronic coughing (National Research Council, 1999).

Cancer of the lung, kidney, liver, and bladder have been observed in countries 20-30 years after known arsenic exposure via drinking wells. The majority of cases documenting human effects from arsenic pollution deal with contaminated drinking water, often from mining drainage.[3] The worst episode to-date is taking place in Bangladesh, where one quarter of the population (120 million) is affected by wells contaminated with arsenic released by natural conditions (Nordstrom, 2002). Drinking water contamination has been or is also occurring at a smaller scale in India, Argentina, Vietnam, Inner Mongolia, Chile, and Mexico (Nordstrom, 2002).

Exposure from air and water is correlated with skin lesions and increased skin, lung, and internal cancers, yet the element does not typically cause tumours in laboratory experiments (Clewell *et al*., 1999). This observation has created a controversial debate over the presence of a threshold concentration, beyond which carcinogenic effects are observed (Clewell *et al*., 1999).

2.1.9 Arsenic Guidelines

Federally accepted thresholds for identifying arsenic contamination in vegetation have not yet been established; too little is known about the element's toxicity in individual species. Researchers instead assess an area based on known and determined background levels. They can then assign health risks based on tolerable daily intake (TDI) guidelines and knowledge of diet. Health Canada and the World Health Organization publish TDI guidelines, which indicate the amount of a substance that is safe to consume on a daily basis. The TDI for inorganic arsenic is currently set at 2 µg/kg body weight/day, although Health Canada is currently reviewing data to reassess this value (M.T. Lo, pers. comm., 2002). No TDI is available for organic arsenic, likely given its low toxicity and consequent low priority.

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[3] Other important sources contributing arsenic in groundwater include organic rich or black shales, Holocene alluvial sediments (with slow flushing rates), mineralized or volcanogenic areas, and thermal springs (Nordstrom, 2002).

Contamination thresholds have been set for soil by various agencies. The Yukon Contaminated Sites Regulation (CSR) was passed in 1996 with the purpose of providing guidelines to identify, manage, and clean up contaminated sites in the Yukon (Department of Renewable Resources, 1996). Standards are provided for agricultural, parkland, residential, commercial, and industrial sites. The Canadian Council of Ministers of the Environment created environmental quality guidelines for water, soil, sediment, air, and marine food in four land use categories: agricultural, residential/parkland, commercial, and industrial. The 1997 soil quality guideline for inorganic arsenic was updated in 2001 (CCME, 2001). For both the CSR and CCME, the industrial land use category is most suitable for this study. A military guideline based on initial investigations of the Distant Early Warning (DEW) Line radar sites prompted the development of the DEW Line Cleanup Criteria (DCC) in 1991 (Environmental Sciences Group, 1995). Table 5 compares these three common environmental criterions consulted by northern researchers for arsenic contamination.

Table 5. Criteria for arsenic contamination in soil in µg/g (ppm) dry weight (from Environmental Sciences Group, 1995; Department of Renewable Resources, 1996; Canadian Council of Ministers of the Environment (CCME), 2001).

Yukon Contaminated Sites Regulation (CSR) (Industrial) Plants[1]	**CCME Guideline Inorganic As**	**CCME SQG$_E$**[2] **Inorganic As**	**DEW Line Cleanup Criteria (DCC)**	
			Tier I[3]	**Tier II**[4]
150	12	50	-	30

[1] Toxicity to plants and soil invertebrates
[2] Soil quality guideline for the environment (as compared to human health)
[3] Tier I-contaminated soil may be placed in an on-site landfill
[4] Tier II-contaminated soil must be entirely removed from the site

The mine sites examined in this study are on federally controlled land and therefore not considered under CSR guidelines; the DIAND Waste Program uses CCME values instead (B. Hartshorne, pers. comm., 2002). However, it is my opinion that the Yukon CSR guideline is the most appropriate for this study: the CCME and DCC guidelines are general values, and are not representative of soil containing anomalous arsenic concentrations. They are of less use in mining regions where gold ore is naturally associated with bedrock containing arsenic. Although the 150 ppm CSR guideline is also a general value, it has taken arsenic-rich soil samples into consideration prior to calculating the final value for industrial sites.

2.2 Studies of Arsenic in Northern Plants

Recent studies have been done on trace metal accumulations in northern vegetation, including studies of arsenic in plants. Research tends to focus on three categories: 1) contributions from local point sources, 2) identifying natural 'baseline' concentrations, and 3) contributions from diffuse sources distributed to northern latitudes via air and water circulation systems.

These categories can be difficult to distinguish though, particularly the latter two, since arsenic is so ubiquitous. Identifying the specific source of the element would require a thorough survey that uses 'fingerprinting' techniques: comparing chemical compositions of local soil, water, and vegetation samples to known industrial sources, and attempting to pinpoint the geographical location of the source. This was done in a recent study of lead in northern vegetation (France and Blais, 1998).

Diffuse sources include arsenic released by volcanic activity and pollution, which can migrate north. However, the general lack of mobility of this element, due to its strong sorption by soil constituents such as clays, hydroxides, and organic material (Kabata-Pendias and Pendias, 2001), suggests that most arsenic in Yukon soils and plants represents local sources or reflects baseline concentrations.

2.2.1 Point Source Studies

Point sources include mining properties, smelters, and military sites. Arsenic results from studies taking place at such locations will be reviewed for purposes of comparison with this study. The mine sites include Mt. Nansen, Arctic Gold and Silver, and Venus Mines in the Yukon, and Giant/Con Mine in Yellowknife, NT, and the smelter is one located in north-western Russia. The relevant military sites include Yukon's Aishihik airstrip, and radar stations in northern Canada.

Many studies show increased arsenic in plants located near mines (Godin and Osler, 1985; Dunn, 1995; Bech *et al.*, 1997; Ashley, 1999; Davey, 1999). While this may be due to uptake from naturally enriched soils, it also indicates the importance of considering airborne sources. One project looked at total arsenic in berries gathered near active mines (Con and Giant), and abandoned mines (Salmita and Burwash) in the Yellowknives Dene traditional territory. Results showed that 21 of 51 berry samples exceeded the contamination threshold of 0.1 µg/g (ppm) (Davey, 1999). This limit was the Health Canada guideline for arsenic in fruit juices, used by the author who recognized that no guideline exists for fruit. The highest (wet weight) concentrations found in individual species were the following: raspberry (1.91 ppm Giant Mine), blueberry (0.16 ppm Salmita), cranberry (0.64 ppm Con Mine), gooseberry (0.20 ppm Giant Mine), rose hip (0.86 ppm Con Mine), and cloudberry (0.32 ppm Salmita) (Dene Nation, 1998). Concentrations in berries from mine sites were significantly higher than those from control sites, and the authors suggest that the mines do have an effect on arsenic levels in berries. A final recommendation was to avoid picking berries in certain locations and wash them thoroughly in other areas.

Other researchers studying arsenic in soil and vegetation around Yukon gold mines also came to these conclusions. The Venus Mine had been mined for close to a century and in 1995, its tailings underwent a cap and barrier wall construction project. The total arsenic content of raspberries was examined prior to, and after this project.

In 1983, raspberries were picked from two sites at the Venus tailings site and on a whim, sent to be bio-assayed (J. Cruikshank, pers. comm., 2001). The results from the fresh berries showed 4.7 and 15 ppm arsenic content, while a sample of preserved jam picked 1.5 km away had <0.20 ppm (referred to in Godin and Osler (1985)). Further testing of vegetation, water, and sediments by Environment Canada's Environmental Protection Service revealed one of five sites with consistent contamination (2.3 to 40 ppm); sand was visible on all samples with elevated arsenic (Godin and Osler, 1985). Signs were erected to warn berry pickers away from the area due to high arsenic concentrations, and clinics were set up to test hair and fingernails for arsenic exposure in local residents - the results of which were negative (Godin and Osler, 1985). In 1984, a thorough study of the vegetation, water, and soil in the vicinity of the Venus tailings was undertaken, and for comparison, sampling at the Mt. Nansen mining area was also performed (Godin and Osler, 1985). The results of the vegetation survey indicated evidence of windborne contamination by sand and dust at the Venus site. Non-rinsed raspberries had significantly greater concentrations than rinsed raspberries at the two sample sites around the tailings pond (36.6 versus 9.6 ppm, and 93.3 versus 33.3 ppm for the Venus and Mt Nansen sites, respectively). Rosehips and gooseberries collected at these same sites also had elevated concentrations, as did the leaves of raspberry, rosehip, and gooseberries shrubs. There was little evidence of arsenic contamination at the Mt. Nansen site as fireweed leaves, and juniper berries, blueberries, and mossberries had arsenic concentrations <1 ppm.

Subsequent raspberry sampling at the Venus tailings showed a decrease in concentrations after the cap was installed. Replicate samples collected in 1995 had a mean of 134.5 ppm wet weight (Roach, 1995), while a 2001 sample was 0.1 ppm (P. Roach, pers. comm., 2002).

A sample collection in 1999 was predominantly carried out at the Arctic Gold and Silver Mine survey (Roach and Cunningham, 2000). Samples collected in the drainage area in between the tailings and a beaver pond yielded high total arsenic concentrations in willow (43.9 ppm) and sedges (4.3 ppm), while bearberry was only 0.6 ppm. Samples collected nearby (off-site along Tank Creek) had less varied total arsenic results: willow (1.95 ppm), sedge (4.56 ppm), bearberry (0.3 ppm), alder (2.5 ppm), and raspberry (4.6 ppm). Since the arsenic was predominantly inorganic, it was recommended that local residents avoid picking raspberries. The Arctic Gold and Silver tailings were capped in 2000 (EBA Engineering Consultants Ltd., 2001).

Barcan *et al.* (1998) examined concentrations of metals and metalloids in berries and mushrooms collected around a nickel-copper smelter at Monchegorsk, Kola Peninsula, Russia. Relevant species include lowbush cranberries, blueberries, and Bolete mushrooms. The researchers found that arsenic concentrations did not exceed health standards: maximum dry weight sample concentrations for the relevant species included 0.37 ppm (*Vaccinium vitis-idaea*), 0.25 ppm (*V. myrtillus*), 1.3 ppm (*Leccinum aurantiacum*), and 0.16 ppm (*L. scabrum*). However, the berries and mushrooms were inedible within a 3000 km^2 area surrounding the smelter complex due to dust emissions causing elevated nickel (and in one area, strontium) concentrations.

An environmental study of Yukon's Aishihik Airstrip was carried out in 1994 (Environmental Sciences Group, 1995). PCB and inorganic element (including arsenic) concentrations were determined in soil, water, and plants collected on-site, and from background areas. Seventeen samples of shrubs (predominantly willow) and grasses were analysed for arsenic; for some samples, the roots and shoots were separated and individually analysed. The study defined plants as being contaminated when their concentrations exceeded twice the background levels, which was determined from 3 willow samples to be <0.2 ppm. On-site, the majority of samples were <0.2 ppm also, with a high range of 0.8 ppm (willow shoots) and 2.6 ppm (willow roots). Soil from the Aishihik Airstrip site was also evaluated using the CCME residential/parkland criteria, and no samples were found to exceed the 30 ppm threshold (range 1.9 to 15.7 ppm). The background levels of arsenic in soil showed a mean of 6.9 ppm (Environmental Sciences Group, 1995).

Dushenko *et al.* (1996) examined 960 plants for PCB and inorganic element concentrations (including arsenic) at 43 sites in the Canadian Arctic. These included 707 plants collected from military radar sites (abandoned or former DEW Line, Pole Vault, or Pine Gap stations), 162 background plants collected up to 10 km away from the military sites, and 91 samples from 6 remote background sites >20 km away from any human presence. Samples comprised leaves, stems, and root tissue, although some samples were subdivided as at the Aishihik site. For the remote background samples (predominantly willow), 29 had detectable arsenic, with a mean of 0.59 ppm, and a high of 8 ppm. For the site background samples, 29 had detectable arsenic, with a mean of 0.69 ppm, and a high of 46.5 ppm.

2.2.2 Studies Determining Baseline Concentrations

A large inventory of traditional diet information was collected from Northwest Territory Dene and Métis groups by Berti *et al.* (1998). The only arsenic concentrations in plants published in the article were for blueberries (2.5 ppm) and cranberries (2.8-3.0 ppm), which are low enough not to be of concern using Health Canada TDI criteria.

Florkiewicz *et al.* (1995) collected 110 plant samples from Yukon's Ross River and Watson Lake communities in 1993. They found no unusually high arsenic concentrations in a pilot study that was intending to capture baseline levels of elements in country foods, including plants used as traditional foods and medicine.

An expanded study (1993-1995) examined samples collected in the communities of Watson Lake, Teslin, Whitehorse, Haines Junction, Ross River, and Dawson (Gamberg, 2000). As with mammal and bird tissues, no elevated arsenic concentrations were found in 107 plant samples. Results are shown in Table 6.

As part of the dietary benefit/risk assessment of >70 species of traditional plant and animal foods consumed by Yukon First Nations, arsenic was analysed in 20 samples of berries collected from Yukon communities. The researchers found that arsenic levels were low in all 171 traditional food samples, including plant foods. All berries had undetectable arsenic concentrations except for one lowbush cranberry sample collected from the Carcross community with 1.3 ppm (Receveur *et al.*, 1998).

Table 6. Mean arsenic concentrations in vegetation collected throughout the Yukon (from Gamberg, 2000). Data are grouped to show relative arsenic concentrations in different plant parts and plant types.

Plant part	**n**	**Arsenic Concentration** (mg/kg dry weight)
Bark	1	<0.01
Berry	46	<0.01
Flowers	9	0.11
Forbs	9	0.29
Evergreens	4	0.07
Mushroom	4	0.8

Koch *et al.* (2000) examined the forms of arsenic available to plants collected around Yellowknife, Northwest Territories. Given the high natural arsenic concentrations in the area, baseline concentrations should exceed that of other regions with different geology. On average, Koch *et al.* (2000) found that mosses had higher total arsenic than grasses/shrubs (825 ppm versus 53 ppm dry weight, respectively), and of this total, inorganic forms were dominant over organic forms. More than 50% of this element could not be extracted by analytical techniques and its form remains unknown. What organic forms that could be extracted and identified include arsenosugars and methylated species. Their percentage of total arsenic ranged from 0-11% (As^{+3}) versus 8-88% (As^{+5}) for the 14 plant species analyzed.

2.3 Introduction to Ethnobotany and Traditional Knowledge

First Nation people are strongly connected to the land, and they have great understanding of biotic and abiotic systems through their historic lifestyle and culture. This traditional knowledge has been passed through generations via an oral history. The working definition of traditional knowledge used by the Northern Contaminants Program is the following:

> An existing Aboriginal knowledge system of lands, waters, climates, seasons and related animal behaviours in an Aboriginal territory, based on ancestral experiences, oral history, subsistence harvesting and traditional use of plants and animals, as well as the use of historical waterways, trails and other nomadic travel paths (Council of Yukon First Nations, 2000).

Traditional and western-based scientific knowledge can be used together to research ethnobotany: the study of plants important to people, which incorporates knowledge of cultural and historic roles, linguistic and botanical classifications, and ecology. Plants have been gathered as food and medicines by First Nations for millennia. Contemporary nutritive and chemical analysis of traditional plants allows an understanding of why these plants remain effective choices. In spite of known contamination in northern ecosystems from pollution sources located in industrialized regions further south (persistent organic pollutants, heavy metals, etc.), the benefits of consuming traditional foods (versus those purchased from the market) outweigh the risks (Wein, 1994; Jenson *et. al*, 1997).

Plants are used daily by northerners throughout the circum-arctic region (Arctic Monitoring and Assessment Programme, 1997). With reference to Yukon First Nation diets, typical edible plants include arctic dock (*Rumex arcticus*), fireweed (*Epilobium angustifolium*), wild onions/chives (*Allium schoenoprasum*), dandelion leaves (*Taraxacum officinale*), wild rhubarb (*Polygonum alaskanum*), bear root (*Hedysarum alpinum*), Labrador tea leaves (*Ledum* spp.), Bolete mushrooms (*Leccinum* spp.), puff balls (*Lycoperdon* spp.), morels (*Morchella* spp.), shaggy mane mushrooms (*Coprinus comatus*), blueberry (*Vaccinium* spp.), crowberry (*Empetrum nigrum*), low-bush cranberry (*V. vitis-idaea*), highbush cranberry (*Viburnum edule*), soapberry (*Shepherdia canadensis*), strawberry (*Fragaria* spp.), cloudberry (*Rubus chamaemorus*), rosehips (*Rosa acicularis*), currants and gooseberry (*Ribes* spp.), and Saskatoon berry (*Amelanchier alnifolia*) (Nardelli and Wein, 1996; Receveur *et al*., 1998; D. Charlie, pers. comm., 2001). Plants are often important sources of vitamin C, vitamin A, calcium, fibre, folacin, thiamine, and fibre (Medical Services Branch, 1994). Some nutrient composition values for selected berries, plant greens, roots, and others are listed in Appendix 1.

Receveur *et al*. (1998) completed a territory-wide study of dietary benefits and risks associated with the consumption of traditional foods by Yukon First Nation people. They had the following observations: 1) traditional foods are consumed 57% of the year (80% in summer, and 40% in winter), 2) 58% of the households surveyed collect plants, 3) plant foods are consumed in summer and to a lesser extent, winter, 4) berries are consumed by the most number of people compared to other plants; in descending order of the top 10 species by summer use (blueberries, wild raspberries, low bush cranberries, wild strawberries, high bush cranberries, soapberries, crowberries, Labrador tea, mushrooms, balsam fir), 5) the youngest generation (20-40) consumes more market food than older generations, including fewer berries, mushrooms, and wild rhubarb (Receveur *et al*., 1998).

Chapter 3: Site Descriptions and Methods

3.1 Study Sites

A general site map showing the locations of the mines and the traditional territories of the two Yukon First Nations is shown on Figure 1.

3.1.1 Mt. Nansen Property

Physical Geography

This site is located ~60 km west of Carmacks, YT (62° 05' N, 137° 05' W), at an elevation between 945 and 1525 m (tailings pond at ~1133 m) (Klohn-Crippen, 1995). Important waterways include Pony Creek and Dome Creek that drain west into Victoria Creek, which in turn drains south into Nisling River. An archaeological site used as an educational camp by the LSCFN is situated several kilometres from the mine near Victoria Lake, a "once favoured fishing spot [that] has been spurned for years now since no one is sure whether the fish are safe to eat or not" (Noble, 2000, 3).

The area experiences a sub-Arctic continental climate, with long cold winters, short mild summers, and low to moderate precipitation (Atmospheric Environment Service, 1993; Jackson, 2000). In a region of discontinuous permafrost, the soil orders found here include Gleysols, Organics, Regosols, Turbic Cryosols, and Eutric Brunisols (Tarnocai, 1987). The area was not glaciated during the McConnell glaciation (which ended ~11,000 years ago) and weathering of bedrock has subsequently occurred in areas to depths of ≤75 m, while leaching and oxidation of sulphides and other compounds have taken place in mineralized zones (Melling, 1994). In the immediate area of the tailings pond, surficial materials of moss, peat, and organic silts and sands overlie glacial till and sands, which in turn cover bedrock (T.W. Higgs Associates, 1994; Klohn-Crippen, 1995).

Broad vegetation types here are coniferous forest on lower slopes and alpine tundra on upper slopes and ridgetops. Local wildlife species include wood bison, woodland caribou, moose, wolf, fox, squirrel, ground squirrel, groundhogs, ptarmigan, grouse, waterfowl, swans, grizzly and black bears (T.W. Higgs Associates, 1994; LSCFN, 1998). Fish are not found in Dome Creek (which directly receives mine discharge) or Victoria Creek, but whitefish and grayling occupy the Nisling River (LSCFN, 1998). During the 2001 field season, moose tracks were observed in the tailings. Ungulate densities around the Mt. Nansen property itself are generally low: moose densities are fewer than 100 per 1000 km^2 (Department of Renewable Resources, 2000), and the wood bison herd has established itself in the Nisling River area ~10-15 km southwest of the mine (T.W. Higgs Associates, 1994). The mine is located in the south-eastern limit of the woodland caribou (Klaza herd) range. However, moose and caribou continue to be hunted in this region. An elder from the LSCFN mentions "the mine site is in the middle of a migration corridor that the caribou use traditionally to get to their wintering grounds" (J.G. Moore & Associates, Ltd, 1998, 14).

The bedrock geology of the Mount Nansen mine environs is complex; rock classes include ultramafics, metamorphics, and volcanics. Samples in this study were largely taken from the PPA regional unit, which is comprised of schists, amphibolite, gneiss, phyllite, quartzite, and ultramafics (Tempelman-Kluit, 1984). Some background samples were located in the DMgPW regional unit that is comprised of amphibolite, schist, and phyllite (Tempelman-Kluit, 1984). The region of the Brown-McDade open pit where the ore was extracted contains andesite, dacite, breccia, tuffs, rhyolite, porphyry, plugs and others of volcanic origin (Tempelman-Kluit, 1984). Bedrock is exposed and shattered on ridge tops and upper slopes of the valleys where there is little or no tree cover (Klohn-Crippen, 1995).

Mining History

The Mt. Nansen property consists of four separate gold and silver deposits: Brown-McDade Zone, Flex Zone, Webber Zone, and Huestis Vein. Underground mining has taken place at Mt. Nansen since 1947, though placer activity has occurred since 1899 (Mineral Resources Branch, 2000). The mill was constructed for a 1967 to 1969 production period, used again during 1975-1976, between October 1996 and February 1999 when BYG Resources Ltd. was in operation, and is used currently for treating water (Mineral Resources Branch, 2000). Prior to the BYG activity, mine workings were small underground gold and silver operations. Ore was brought to the mill and processed using flotation, and tailings were deposited in two small ponds. An aerial photograph of the property taken in 1990 shows the position of the tailings ponds in relation to Dome Creek, as well as exploration trenches for the Brown-McDade open pit (Figure 2). Mine waste from this period is estimated as the following: 25,000 tonnes sulphide-rich tailings and 41,000 tonnes of stockpiled ore near the mill plus an ore dump at Pony Creek (Brodie, 1998; Mountjoy and Ramsay, 2000).

The BYG set-up was both an underground and open pit extraction of ore. The mill was retrofitted to accommodate a carbon-in-leach process for producing gold and silver (T.W. Higgs Associates, 1995). A new tailings pond was constructed on the Dome Creek valley floor ~1.5 km downstream from the mill using local fill material for the impoundment, and the creek itself was diverted (Mountjoy and Ramsay, 2000). Infrastructure difficulties arose from placing the pond over permafrost. Thaw problems led to dam erosion and instability concerns, as the material has the ability to liquefy and "pipe" when thawed (Mountjoy and Ramsay, 2000).

From the reported 788,000 tonnes of rock excavated by the BYG operation by the end of 1998, an estimated 513,000 tonnes of waste rock was produced (Hureau, 1999). It consisted of clay-altered granodiorite and felsic porphyry rock types, and was located adjacent to the Brown-McDade adit to the northeast and to the west. An estimated 258,174 m^3 of tailings was also produced and placed in the 294,000 m^3 capacity pond (Mountjoy and Ramsay, 2000).

Water Resources, a division within DIAND, seized the property in 1999 after BYG violated their water license conditions. The company was fined the maximum amount of $100,000 per charge for not meeting effluent quality standards, exceeding the allowable cyanide concentration in the tailings pond, and for not filing a required chemical analysis report (Steele, 1999). The fourth violation of mining past the oxide zone into the lower sulphide zone (which induces metal leaching), did not go before the Yukon Territorial Court (van Dijken, pers. comm., 2001). BYG's environmental legacies include a structurally unstable dam, metal leaching in the Brown-McDade pit walls and floor, and in the tailings dam where the sulphide-rich tailings were deposited along with oxide tailings, and high cyanide, copper, zinc, and arsenic levels in the pond.

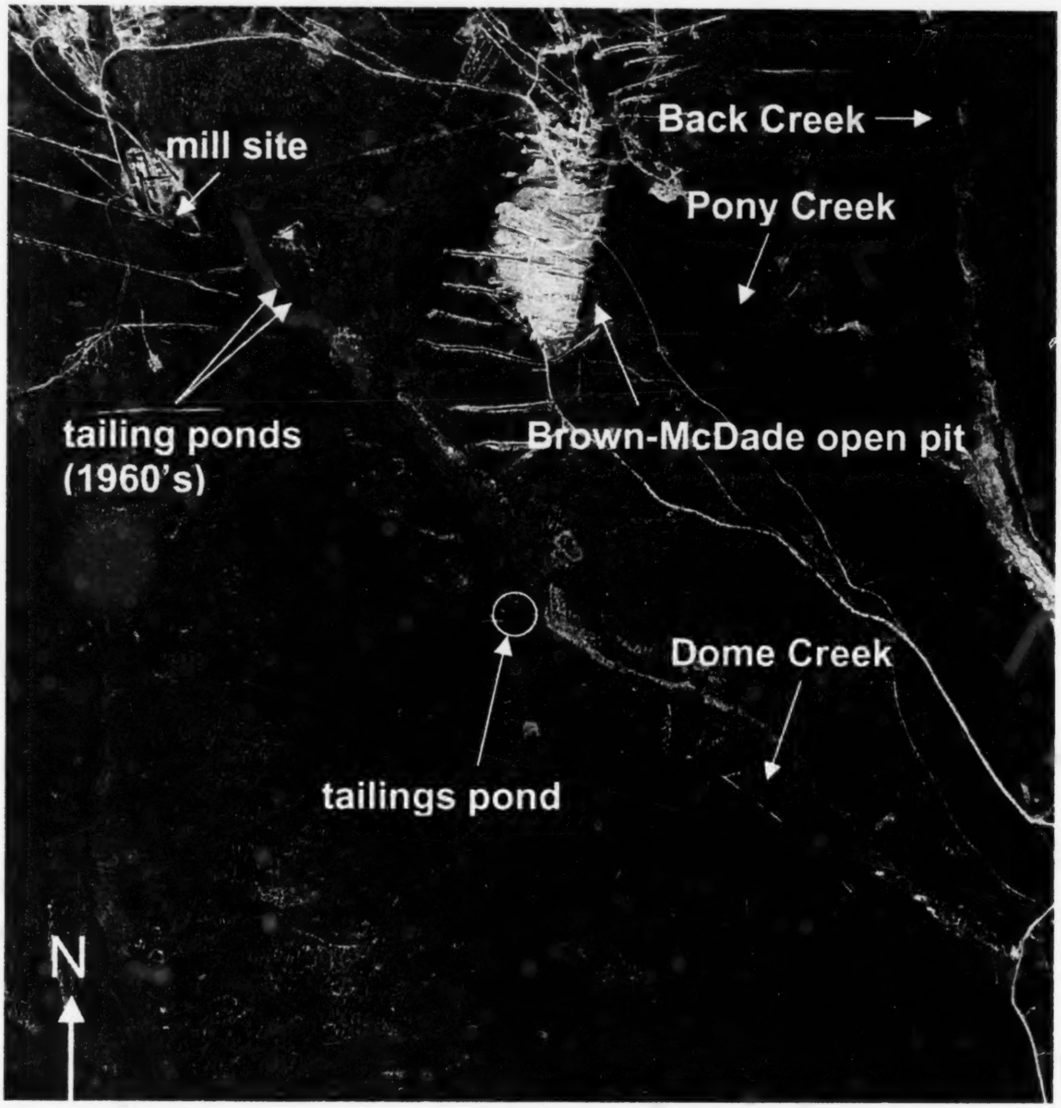

Figure 2. Mt. Nansen aerial photograph showing the tailing ponds, Brown-McDade open pit, and Dome Creek in 1990 (Geographic Data, 1990a). The scale is ~1:20,000.

Reclamation Activities

BYG went into receivership in March 1999, but the receiver (D. Manning and Associates Inc.) gave up property responsibilities in July 1999. The federal government contracted general site cleanup duties to Ketza Construction Ltd. A larger seepage collection dam and pump-back system was installed to reclaim and treat water, as part of the ongoing wastewater treatment program initiated by BYG in fall 1997. Cleanup and reclamation is expected to cost $8-10 million at the cost of DIAND, who has already spent $1.7 million (including BYG's $455,000 water license security) as of November 2000 (P.H. Beaubier, pers. comm., 2000). Reclamation will not occur until the current operator (Water Resources) abandons the site such that the Contaminants and Waste Management Division can step in, and when sufficient funds are available (P. Roach, pers. comm., 2002).

3.1.2 Venus Mine Property

Physical Geography

The Venus Mine tailings site (60° 02' N, 134° 37' W) is 22 km south of Carcross, YT at an elevation of 670 m. It is located on a narrow strip of land bordered by the Klondike Highway #2 to the east, and Windy Arm of Tagish Lake to the west. The abandoned mine site is 2 km further south on the west side of the highway at an elevation of 670-960 m (Environmental Services, 1997).

As with Mt. Nansen, this area experiences a sub-Arctic continental climate though the temperatures are more moderate and precipitation is less here (Atmospheric Environment Service, 1982). Permafrost is very discontinuous in this region. Local soils are predominantly Dystric Brunisols, with Cryosols existing over permafrost. A typical soil profile would be a silty clay layer overlying a permeable sand and gravel layer (Westermann and Nahir, 1999). Vegetation is dominated by coniferous forest and alpine tundra. Local wildlife includes Dall's sheep, moose, wolf, porcupine, grizzly and black bear, grouse, ptarmigan, peregrine falcon, golden eagle, and waterfowl birds such as mergansers (Environmental Services, 1999).

The tailings site is located in the Nakina Formation of the Cache Creek Group. The bedrock class here is volcanic, with the main rock type largely greenstone/metabasite, with hornblende diorite, chert, and carbonate. The geology in the region of the mine is the Montana Mountain Volcanics, comprised of regions with either rhyolite, or andesite and dacite. The ore itself is predominantly arsenopyrite, and has been estimated at 10% arsenopyrite, 8% iron pyrite, and quartz (Jack, 1981).

Mining History

The Venus vein is a gold/silver/lead/zinc quartz vein, and all four of the metals have been excavated. Underground mining activity has taken place here since the turn of the century. In 1966, Venus Mines Ltd. began exploration and by 1970, a 272 tonne/day capacity mill had been built just north of the current tailings about 2 km north of the mine (Environmental Services, 1997). This mill only operated from September 1970 to June 1971, and tailings were deposited in a natural depression with perimeter dikes constructed using the area's natural clay and silt soil layer (Jack, 1981; Klohn-Crippen, 1995). A decant pipe was installed to drain water from the pond. Aerial photographs of the tailings pond are shown in Figures 3A and 3B.

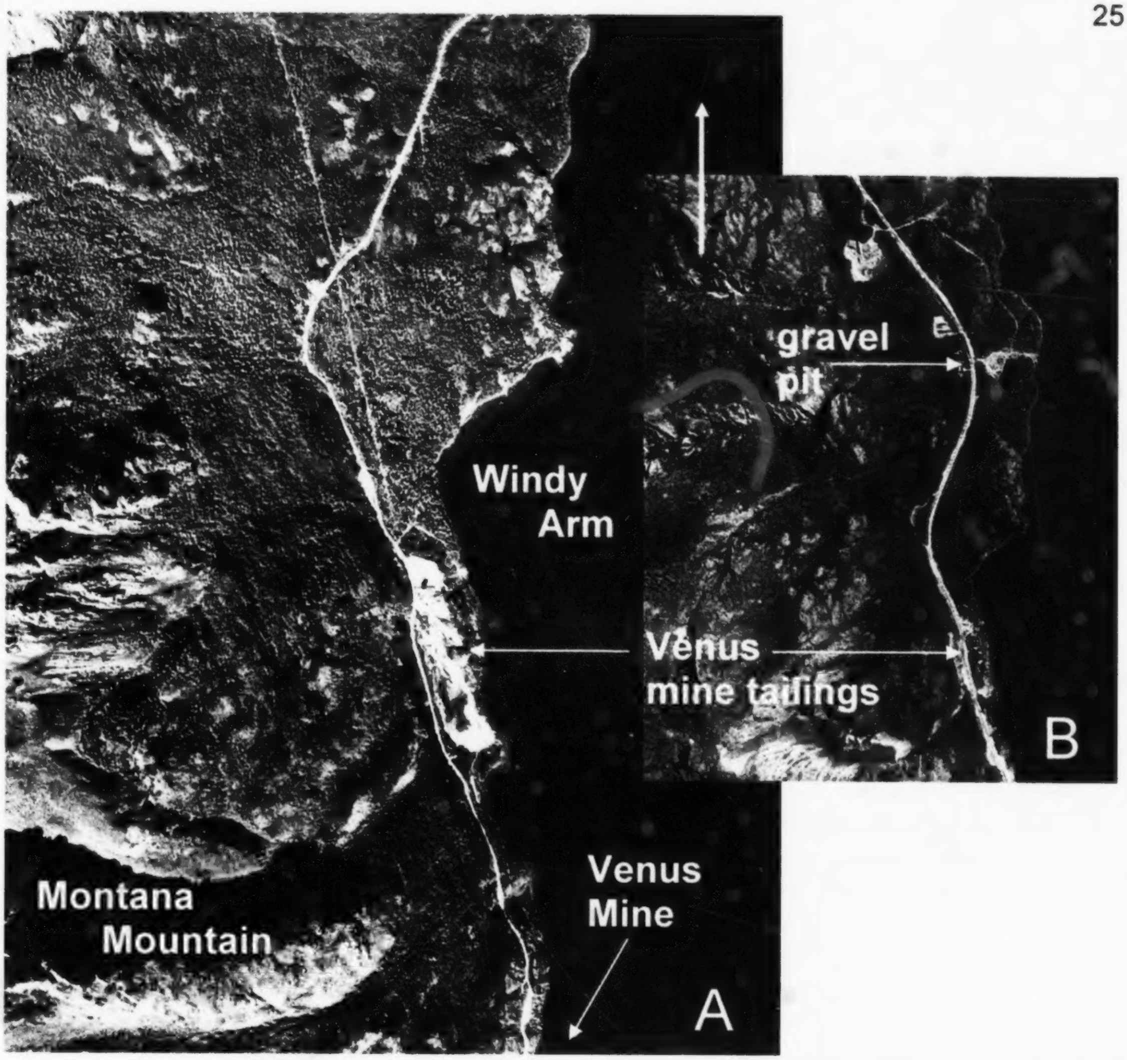

Figure 3. Aerial photographs of the Venus tailings pond showing its proximity to Windy Arm of Tagish Lake and Montana Mountain as shown in A) 1975, scale ~1:4000 (Geographic Data, 1975) and B) 1990, scale ~1:20,000 (Geographic Data, 1990b).

United Keno Hill Mines Ltd. (UKHM) optioned the Venus claims from 1978, and in 1979, they decided to re-open the mine (Environmental Services, 1997). UKHM began construction on a new Venus mill and tailings impoundment in BC, 33.6 km from Carcross and less than 10 km south of the mine. The new mill was built with the expectation that the old tailings would be transferred from their existing site, and reprocessed. By 1981, mine closure occurred due to overestimates of ore reserves, falling metal prices, and environmental problems. Processing of ore had not yet occurred, and the 1970's tailings remained in their current location (with the exception of 360 tonnes that were excavated in 1981 (Klohn-Crippen, 1995)). Estimated tonnage of tailings based on production reports from this period ranges from 51,700 - 54,400 tonnes (Klohn-Crippen, 1995). Calculations based on auger samples collected prior to the excavation suggest a volume of 39,900 m^3 in a tailings pond area of 32,775 m^2 (285 m x 115 m) (DIAND Technical Services, 1993a).

Reclamation Activities

In 1993, under the auspices of DIAND's Arctic Environmental Strategy - Action on Waste program, the environmental impact of 49 abandoned mining properties was assessed, and recommendations for remediation were suggested. The Venus Mine tailings site was not the focus of the Venus Mine property report, but was identified as having potential environmental concerns. Wind and water erosion of the tailings were causing health, water quality, and aesthetic concerns about this highly public site along a major tourist route.

A number of water quality tests on tailings pond water, Venus Mine adit drainage, Windy Arm lake water, sediments, fish and invertebrates have been performed since 1975 (Robson and Weagle, 1978; Jack, 1981, Godin and Osler, 1985, Environmental Services, 1997). Water quality results were generally poor, but the studies showed that high arsenic concentrations released from the tailing site and adits had no or little impact on lake organisms. High arsenic and metals are naturally present in Montana Mountain soils and sediments, and arsenic found in Windy Arm is attributed to a number of sources, of which Venus Mine is only one (Mann, 1998). However, the arsenic found in surrounding vegetation was attributed to the tailings (as discussed in section 2.3.1).

Further assessment led to the decision to consolidate, impound and cap the eroding tailings (the mill had already been removed because of the 1993 assessment). The site underwent rehabilitation work between August 11 and October 20, 1995 when the following components were installed at the cost of $1.2 million: a Waterloo Barrier sheet pile wall; a multi-layered cap comprised of a geotextile, silty clay, and drain rock on top; a plug to a decant pipe outlet; and a drainage discharge system (Vallerand, 1995; Westermann and Nahir, 1999).

In addition to containing the pond area tailings with a barrier wall, 3656 m^3 of windblown tailings were excavated and placed in the pond area (Vallerand, 1995). After the cap was constructed, the land surrounding the tailings site was transferred to the CTFN as part of their land claim (MINFILE, 1998). In 1997, a sand and gravel buttress to support a potentially unstable section of the wall was constructed, and additional material was placed on areas of the cap that were settling or where water was ponding on the surface. Drain rock was again added in 1999 for aesthetic purposes, and to make certain further ponding would not occur (Westermann and Nahir, 1999).

Acid rock drainage (ARD) was an early concern that has now been diminished by using the aforementioned multi-layered cap design. ARD forms when four factors are present: exposed sulphide minerals (e.g. pyrite), oxygen, water, and the bacteria *Thacillus ferrooxidans*. Though the bacteria are present at this site, and the metal-rich tailings are acid-generating, the neutralization potential of the ore is currently high enough that the acid is neutralized (pH tests of the decant water are consistently alkaline) (Davidge, 1984; Poushinsky Consulting Ltd., 1994). The cap design further reduces ARD potential by using multiple layers that submerge the tailings in groundwater that is draining through the cap, thereby reducing the oxygen concentration.

After arsenic levels in berries were tested in the early 1980's, the Carcross community heeded attention to the signs and avoided the area, in spite of the site being a traditional harvesting site by the Carcross/Tagish First Nation (H. Gatensby, pers. comm., 2001). Since the 1995 capping, subsequent tests on the berries have increasingly pointed to this site as a place to pick berries once again.

3.1.3 Arctic Gold and Silver Mine Property

Physical Geography

This abandoned mill and tailing site is located 4 km SW of Carcross (60° 05' N, 134° 41' W) at approximately 1000 m.

The majority of physiographic details provided for the Venus site apply to AGS. The climate would be slightly modified due to the higher elevation of the tailings site, as well as other factors such as slope and aspect. The local vegetation is of the subalpine type, with white spruce, alpine fir, white birch, and alder in cleared areas (Environmental Services, 1998).

The bedrock geology of the immediate region is classified as Carcross granite, within the Nisling Range Plutonic suite. The main rock types include quartz monzonite, granite, alaskite, and granodiorite (Hart and Radloff, 1990). The ore processed at the mill came from mines further up Montana Mountain, which are in a region of (altered) Montana Mountain Pluton granite from the Mt. McIntyre Plutonic Suite (Mann, 1998).

Mining History

The mining claims associated with the Arctic Gold and Silver tailings site include Arctic Caribou, Big Thing, Peerless, and Pride of Yukon. All were underground gold and silver deposits and were located approximately 4 km further south at an elevation of 1500-1700 m (Arctic Caribou) and 1600-1700 m (Big Thing). These claims were staked as early as 1905, and worked between 1910 and 1922 and again during 1966 to 1969 by Arctic Mining & Exploration Ltd (whose name changed to Arctic Gold and Silver Mining Ltd. in 1968) (DIAND Technical Services, 1993b). In June 1967, construction began on a 272 tonne/day capacity mill and concentrator that operated during May-December 1968 and March-October 1969 (DIAND Technical Services, 1993b). The mines were not very profitable however, as the mill closed down having only processed a total of 50,751 tonnes of ore after these two seasons (Environmental Services, 1998). The ore was separated using flotation. During this time, the mill discharged approximately 27,000 m^3 tailings into the 24,700 m^2 (190 m x 130 m) pond area (Environmental Services, 1998; EBA Engineering Consultants Ltd., 2001).

Reclamation Activities

The mill and tailings impoundment site was not listed among the 49 mining properties assessed by DIAND in 1993, though the mines that fed the mill were included. Due to concerns about environmental quality raised by the Carcross/Tagish First Nation, government and other interested parties, the site was assessed in 1997. Assessments revealed windblown tailings along the northeast edge of the impoundment, as well as tailings spilling into an unnamed pond 80 m to the west via a decant pipe. The pond was originally a marsh from which Tank Creek flowed, discharging to Bennett Lake. At an access road at the north end of the marsh, the creek was diverted into a 1 m culvert. Beavers built a dam over this culvert to create a pond. The tailings site is shown in a 1995 aerial photograph (Figure 4).

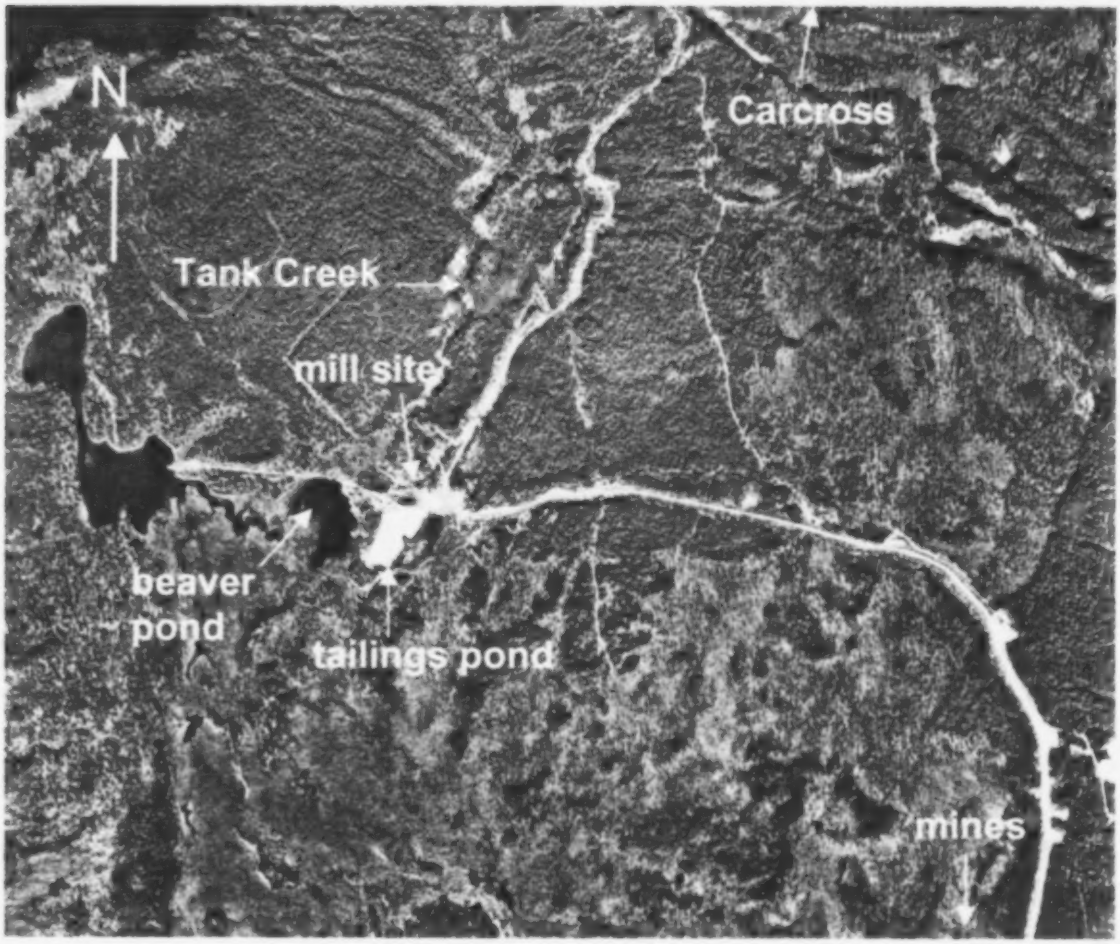

Figure 4. Aerial photograph of the Arctic Gold and Silver property showing the mill, tailings pond, and Tank Creek in 1995 (Geographic Data, 1995). Scale is ~1:20,000.

Water quality studies provided evidence that the tailings were acid-generating (Environmental Services, 1998), and elevated arsenic, iron, and sulphate levels in Tank Creek had been recorded as early as 1976 (Weagle *et al.*, 1976). These studies did not show that aquatic biota was impacted (Weagle *et al.*, 1976; Roach, 1997). However, there was evidence of contamination in the surrounding terrestrial vegetation (as discussed in section 2.3.1).

After another environmental assessment, the decision was made to re-collect the eroded tailings and to place them into a capped impoundment. The mill had already been taken out, but the recommendation to remove its concrete foundation was also made (Environmental Services, 1998). When the tailings were re-collected in the summer of 1999, the dam was destroyed and the area turned back into a marsh. Between July 1999 and September 2000, the tailings were covered with a low permeability cap designed to prevent ARD production by eliminating the factors of water and oxygen. The cap comprised a layer of local sand, gravel and cobbles, which was overlain by a layer of clayey silt (EBA Engineering Consultants Ltd., 2001).

3.2 Sampling Methodology

The field season (comprising of site assessment, interviews, and sampling) took place between July 11 and Aug 29, 2001. Important local plants were initially discussed with members of the Little Salmon/Carmacks First Nation, and the Carcross/Tagish First Nation. Elders provided their perspectives on local vegetation: food and medicinal uses, cultural importance, and general ecological knowledge. Several knowledgeable younger people provided input as well. The intent of the interviews was to determine which species were most important to study, given that not every species would be found at all the mine site locations. Consequently, although berries comprised the majority of species that were eventually sampled, the importance of yarrow, birch, rose hips, and spruce pitch arose during discussions with the Elders.

The eight interview participants had grown up in the region of the mine sites and/or were well acquainted with plant medicine. Many conversations included a "show and tell" component – trips to a garden or habitat near the community, or bringing medicine out from storage, such that a visual description of the species being discussed could be provided. For instance, W. Atlin (pers. comm., 2001) pointed out rosehips in her Carcross garden and mentioned that eating three roasted rosehips per day would prevent getting a cold. Athapaskan (Tutchone and Tagish) and Tlingit (Inland Tlingit) traditional names of these common local plants were obtained through the consultations, and with the use of language and historical books (Appendix 2).

Sampling at each mine site followed a transect design such that plants and soil were collected from three locations: adjacent to the tailings or other point source of contamination, 1-3 km away, and background samples collected up to 20 km away. General sampling locations for Mt. Nansen are shown in Figure 5. Figure 6 shows the sampling locations for the Arctic Gold and Silver and the Venus Mine tailing sites.

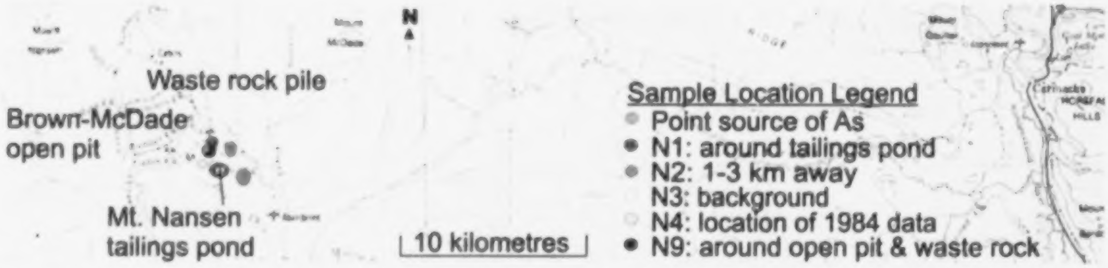

Figure 5. Sampling locations at the Mt. Nansen study site, including background and point source locations.

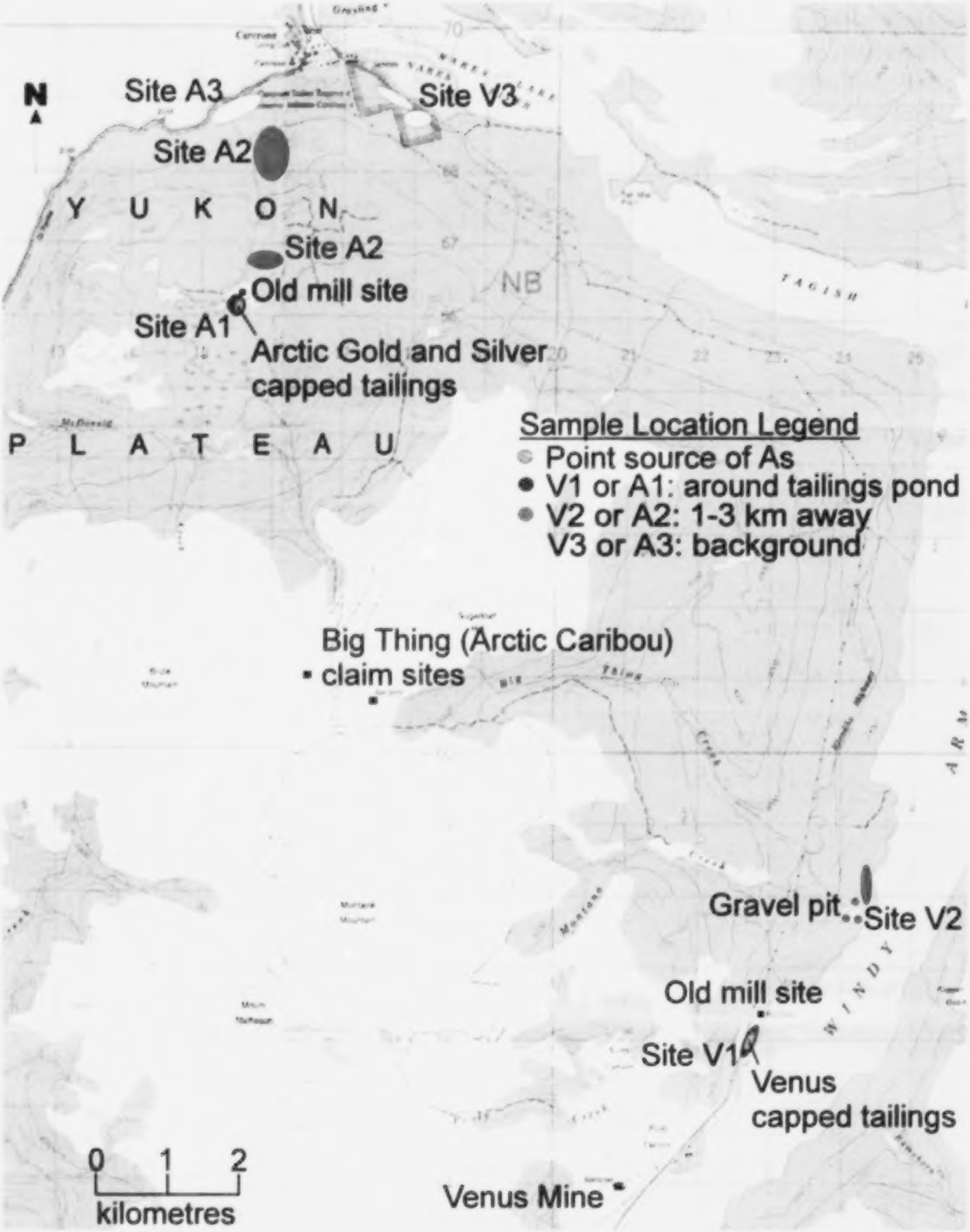

Figure 6. Sampling locations for the Arctic Gold and Silver, and the Venus Mine tailing sites.

Geology, dominant wind direction, and historical land use were conditions considered when choosing sample areas. In order to compare temporal trends, attempts were made to collect species that had been sampled in previous studies (e.g. raspberries at

Venus, and mossberries at Mt. Nansen). However, this was occasionally not possible due to the absence of ripe fruit (e.g. raspberries at Arctic Gold and Silver).

The majority of plants sampled were berries, which are predominantly used for food and have historic ceremonial and cultural significance (Thornton, 1999); other species are foods of foraging animals harvested by the First Nations (e.g. caribou, moose, squirrels, ptarmigan, and grouse). All plants collected in this study have medicinal uses. Table 7 shows the plants that were sampled and analysed for arsenic content at each of the three mine sites.

Table 7. Breakdown of samples analysed for arsenic content at each mine site.

Species	Tissue Type	Sites			Total
		Mt. Nansen	AG&S	Venus	
Blueberries (*Vaccinium* spp.)	berry	22	0	0	**22**
Lowbush cranberries (*V. vitis-idaea*)	berry	23	0	0	**23**
Labrador tea (*Ledum groenlandicum* and *L. decumbens)*	shoot	21	0	0	**21**
Bolete mushroom (*Leccinum* spp.)	stem	21	0	0	**21**
Caribou moss (*Cladina mitis* and *Cetraria nivalis*)	thallus	21	0	0	**21**
Willow (*Salix* spp.)	stem	22	0	0	**22**
Willow (*Salix* spp.)	leaves	22	0	0	**22**
Crowberries (*Empetrum nigrum*)	berry	22	0	0	**22**
Soapberries (*Shepherdia canadensis*)	berry	0	10	0	**10**
Raspberries (*Rubus acaulis*)	berry	0	0	12	**12**
Soil	N/A	23	10	9	**42**
Total		**197**	**20**	**21**	**238**

At least three samples of a plant species were collected from each location. Species were identified using plant guidebooks, and sample locations were recorded using a hand-held GPS unit (Garmin 12XL). Samples were photographed *in situ*, prepared, and stored frozen. Preparation included creating voucher specimens, separating willow leaves and stems, removing the mushroom cap from the stalk, cleaning lichen of leaf matter, and rinsing mushroom stems, willow leaves and Labrador tea shoots twice in de-ionized water.

At least three samples of soil were also collected at each location (0-10 cm depth) using plastic scoops and Whirlpak™ bags to minimize external contamination.

Samples were shipped frozen to either UBC or Enviro-test Laboratories. The collection of 424 samples was prioritized in fall 2001, during which time the budget was finalized.

A total of 238 plant and soil samples were selected for inorganic and organic arsenic analysis: 197 from Mt. Nansen, 20 from the Venus tailings, and 21 from the Arctic Gold and Silver site (Table 7). All other samples remain in frozen storage at UBC.

Emphasis was placed on collecting and analysing plants from Mt. Nansen because this site has not yet been cleaned up unlike the other two sites, and arsenic data from plants has not been collected from here since 1984. Species chosen for analysis were those repeatedly mentioned by community residents, and also sufficiently abundant in the vicinity of the mine. For example, puffballs and cloudberries are important local plants to the Little Salmon/Carmacks First Nation, but were not found growing at each of the three locations around a particular mine, and therefore were excluded from the final list of samples to be analysed. Other species were excluded because of their apparent lesser significance to First Nation members (for example, although rosehips, Labrador tea, willow, and goose-berries were present around the Venus Mine, raspberries were the species most often picked there by local residents).

3.3 Laboratory Analysis

Enviro-test Laboratories in Edmonton, AB was chosen to analyse the samples in this 2001 study because the company had previously analysed organic and inorganic arsenic concentrations in plant tissues from the Venus and the Arctic Gold and Silver sites. Their analytical technique was developed for a previous study, and is not common in the literature. Most commercial and university labs can only analyze for total arsenic, while a few university labs are capable of speciation techniques that allow the concentration of specific compounds to be determined (e.g. As^{3+}, As^{5+}, or arsenosugars). The preparation and analysis procedure followed by Enviro-test (H. Zhao, pers. comm., 2002) is described here: samples selected for analysis were freeze-dried (plant tissue) or oven-dried (soils), ground, and then separated into two parts. One part was wet-ashed, digested, and analysed for total arsenic using an Inductively Coupled Plasma Mass Spectrometer that had a detection limit of 0.05 mg/kg for plant tissue and 0.1 mg/kg for soils. The other part was used to obtain inorganic arsenic values by first extracting arsenic from the sample with 20% HCl (EPA procedure 1632), mixing part of the extraction with HBr-Hydrazine sulphate, and then using hydride generation Atomic Absorption Spectroscopy. Organic arsenic was then calculated from the difference between total and inorganic values. Results were reported in both (as-received) wet weight and dry weight, using moisture content to convert the former.

Quality Control (QC) data confirm that analysis methods were recovering and accounting for all the arsenic present, and ensured that instruments were properly calibrated. Reported and internal laboratory QC checks used by Enviro-test included the use of standard certified reference materials (CRM's), sample matrix spikes, system and method blanks, sample duplicates, continuing calibration verification standards, and alternate source standards. CRM's are available for total arsenic tests (using NIST 2709 SOIL and NIST 1575 PINE NEEDLES); however there are currently no CRM's available for inorganic arsenic.

A QC report for total arsenic was sent on June 17, 2002, along with QC for the 19 re-checked samples, followed on June 18, 2002 by a revised spreadsheet of the final results due to two incorrectly entered results. All QC data from both the total and inorganic arsenic analyses were acceptable, using default limits recommended by the US EPA.

3.4 Statistical Analysis

Statistical analysis was performed using JMP-IN version 4.0.3 (SAS Institute Inc., 2000). Prior to using the JMP-IN program, the inorganic and organic arsenic concentrations provided by Enviro-test were added together to obtain total arsenic. Undetectable concentrations were assigned a 0.001 ppm value in order to be able to statistically analyse these data. The distribution of all arsenic data sets (total, inorganic, and organic) for each species was then examined. The Shapiro-Wilk goodness-of-fit (or W statistic) test was used to check for normality, and outlier and quantile box plots identified outliers. A nonparametric analysis of variance (ANOVA) was performed using the Wilcoxon/Kruskal-Wallis Rank Sum test (_ = 0.05). ANOVAs were carried out using the Fit Y by X function where Y = arsenic (dry weight; either total, inorganic, or organic arsenic) and X = Location). If the data were not normally distributed (the situation for 11 of 13 species for all arsenic data sets), six common transformations were attempted: $\log(x+1)$, $\sqrt{x+0.5}$, $\log 10(x+1)$, $\arcsin(\sqrt{x})$, $\log(x)$, and $\sqrt{x}+\sqrt{x+1}$. In 45% of all cases where transformations were attempted, the data could be transformed to normality.

Species data that were normally distributed were then tested parametrically. Tests for equal variance, e.g. O'Brien's test, (SAS Institute Inc., 2000) were used to indicate whether heteroskedasticity was present. In data sets where unequal variance occurred, the variance-weighted Welch F test (Welch's approximate *t*) was used. The variances were considered unequal if the p value for either F test was small (≤0.05). Given the nature of the data, Tukey-Kramer's HSD was deemed most suitable as a post-hoc test for differences among means (Zar, 1984). The underlying geology of the sample locations was then tested as a nested variable in the ANOVAs.

The remaining species that were not initially distributed normally were tested nonparametrically. Dunn's test, as provided in Zar (1984), was used to determine differences among means, similar to the Tukey-Kramer's HSD test for normally distributed data. The species data were then ranked such that the new data could be treated parametrically and checked for normality, significant means, and equal variance. The rank transformation method is straightforward, easy to use, and acceptable for multi-factor analyses (Conover and Iman, 1981; Potvin and Roff, 1993; Johnstone, 1995). Geology was then examined as an explanatory variable.

Detailed statistical analysis results for the data sets are displayed in Appendix 3.

Chapter 4: Results

Results support other studies that found plant uptake was low compared to soil concentrations. Mean total arsenic concentrations in plants at all mining properties ranged from undetectable to 31.1 ppm (Figure 7), while mean total soil concentrations ranged from 9.087 to 11373 µg/g (ppm) (Figure 8). Berry species had little or undetectable mean total arsenic (< 1.3 ppm), and medicinal shrubs (Labrador tea, willow leaves, and willow stems) had <16.7 ppm mean total arsenic. Higher arsenic concentrations were found in plant and soil samples collected around the point source(s) of contamination, and concentrations decreased with increasing distance (Figures 7 and 8, respectively). This was the trend generally observed at all the tailing sites (mushrooms were the only significant exception at the Mt. Nansen site).

The dominant form of arsenic was inorganic, both in soil (Figure 9) and plants (Figure 10). Of the samples with detectable arsenic, the organic form was absent in blueberry and cranberry (Figure 11).

Organic arsenic may not have been present in all soil samples, but the mean concentration in soils for any particular location shows that arsenic was detectable (Figure 12).

A Biological Absorption Coefficient (BAC) indicates the ratio of an element concentration in a plant to the same element concentration in the surrounding soil (Kovalevsky, 1969; Kabata-Pendias and Pendias, 2001). Mean arsenic ratios were generally low (<2.5) for all locations (Figure 13); values greater than one reflect high arsenic values in plants growing in soil with low concentrations for some individual soil and plant pairs. The BAC values for berries did not exceed 0.015, and ranged from 0.02 (N1) to 0.11 (N2) for mushrooms. The highest BAC values were found in caribou moss and the medicinal shrubs: caribou moss ranged from 0.1 (N3) to 2.5 (N2), Labrador tea had less than 1.8, and willow did not exceed 0.62. There was no apparent trend in the locations yielding the highest BAC values, as both N1 and N2 had equal contributions. The BAC values are likely underestimates because of assigning 0.001 ppm to samples less than the detection limit.

4.1 Mt. Nansen Mine Site

Blueberries (*Vaccinium* spp.)

Blueberries had less than detectable arsenic for 19 of 22 samples. The highest detectable arsenic concentration was 0.5 ppm, from an N2 sample collected ~40 m west of the upper old tailings pond and near the edge of Dome Cr. The other two detectable samples (0.3 ppm) came from a site ~5 m west of a N-S oriented access road running parallel to the Brown-McDade open pit, and from a site ~500 m down Dome Creek from the tailings pond on the north side. Non-parametric ANOVA showed no significant differences between the means of N1, N2, and N3 for all three arsenic data sets (Figures 7, 11, and 14).

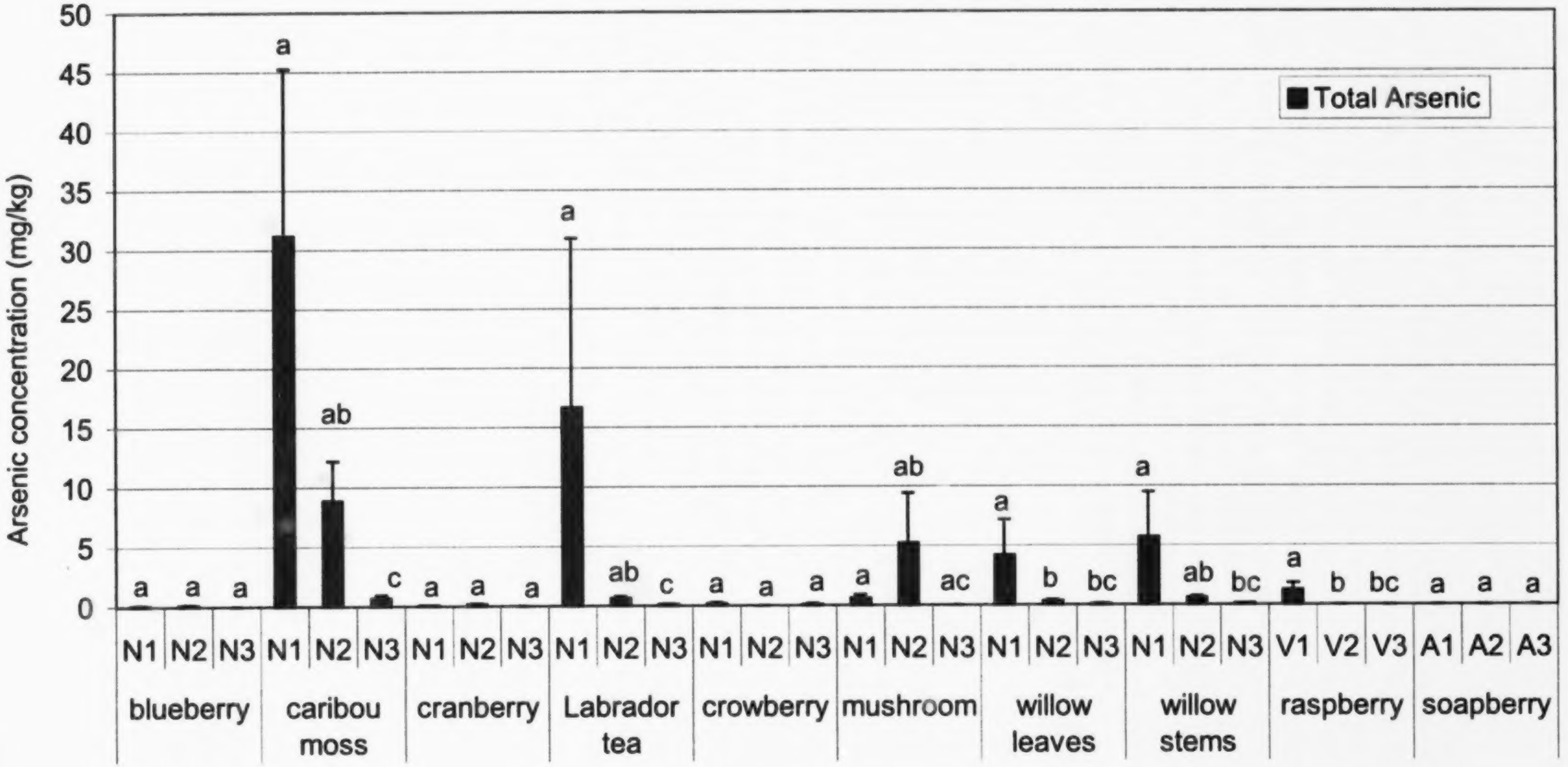

Figure 7. Mean total arsenic concentration (±SE; dry weight) in plants collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Means with the same letter within a species are not different (p=0.05).

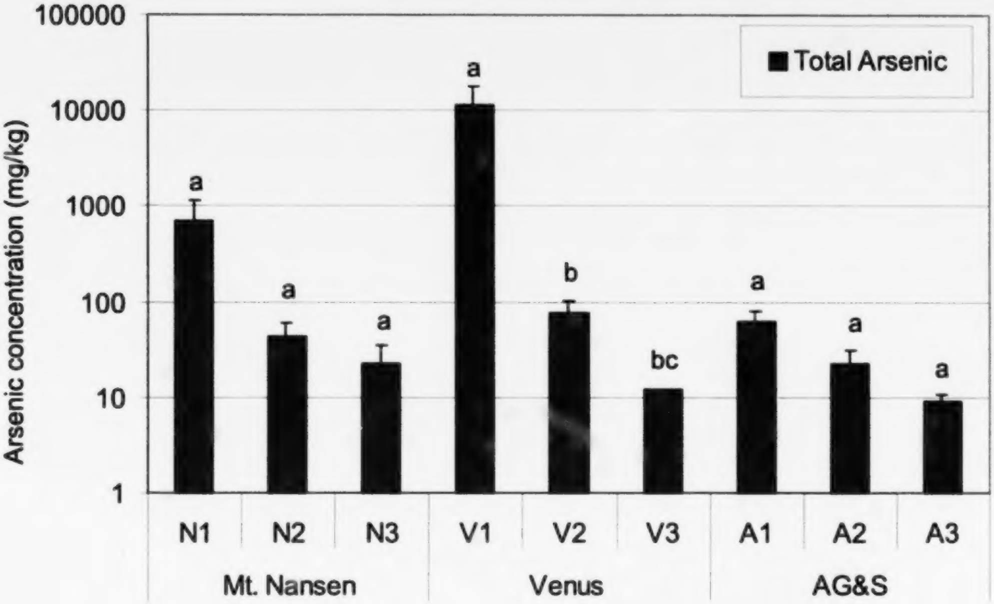

Figure 8. Mean total arsenic concentration (±SE; dry weight) in soils collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Means with the same letter within a species are not different (*p*=0.05).

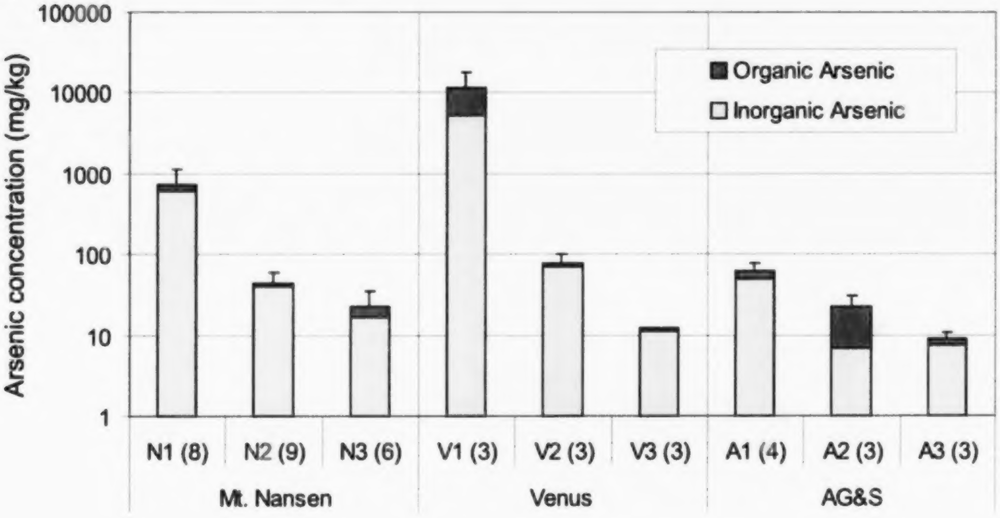

Figure 9. Mean arsenic concentration (dry weight) in soils collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Sample size is shown in brackets. Standard error bars are shown for total arsenic concentrations.

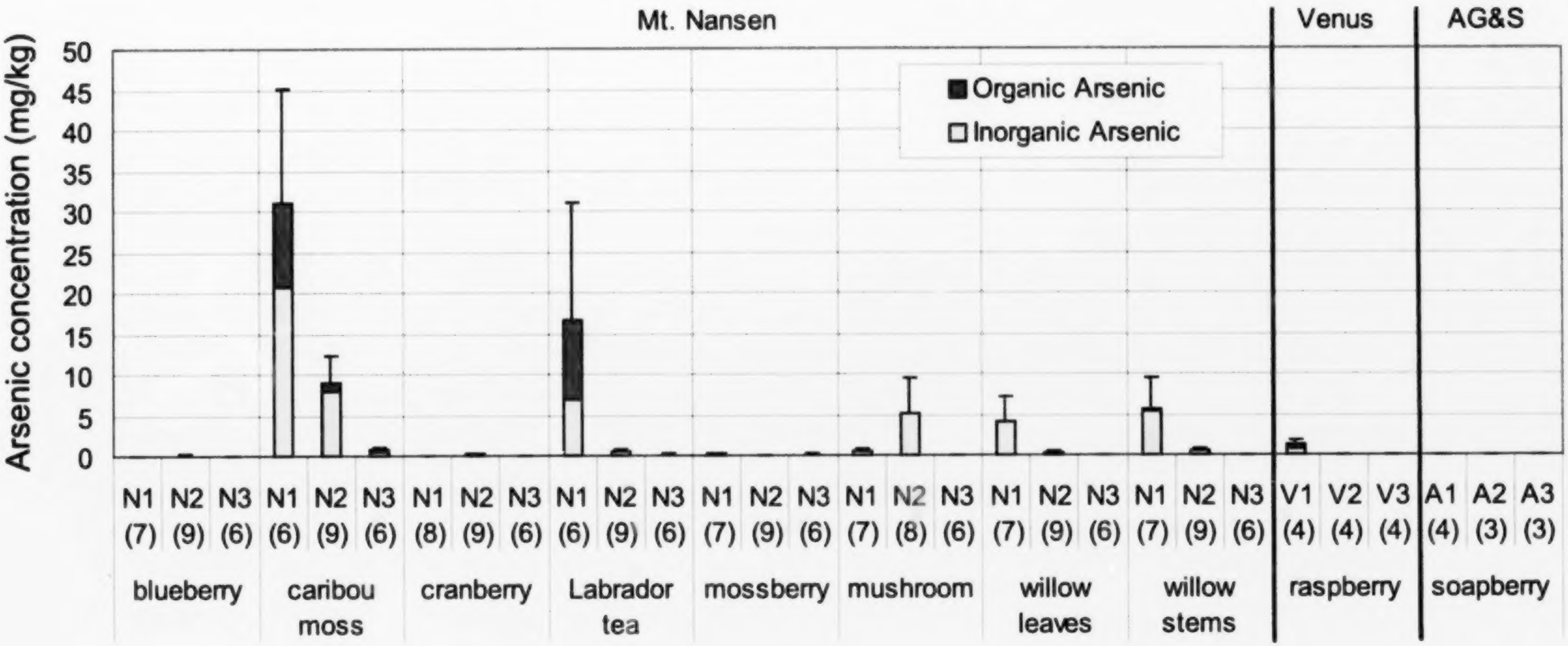

Figure 10. Mean arsenic concentration (dry weight) in plants collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Sample size is shown in brackets. Standard error bars are shown for total arsenic concentrations.

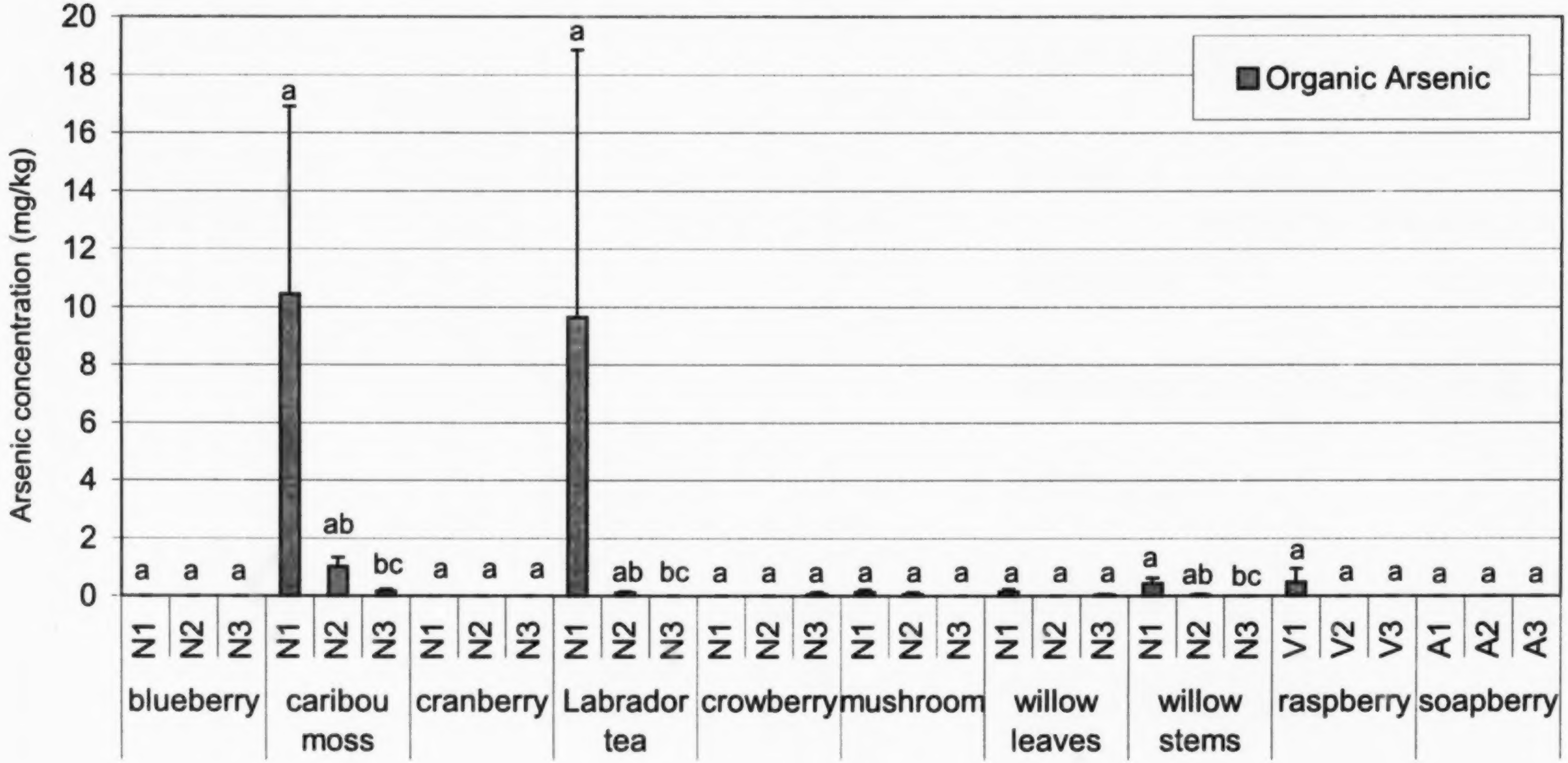

Figure 11. Mean organic arsenic concentration (±SE; dry weight) in plants collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Means with the same letter within a species are not different (*p*=0.05).

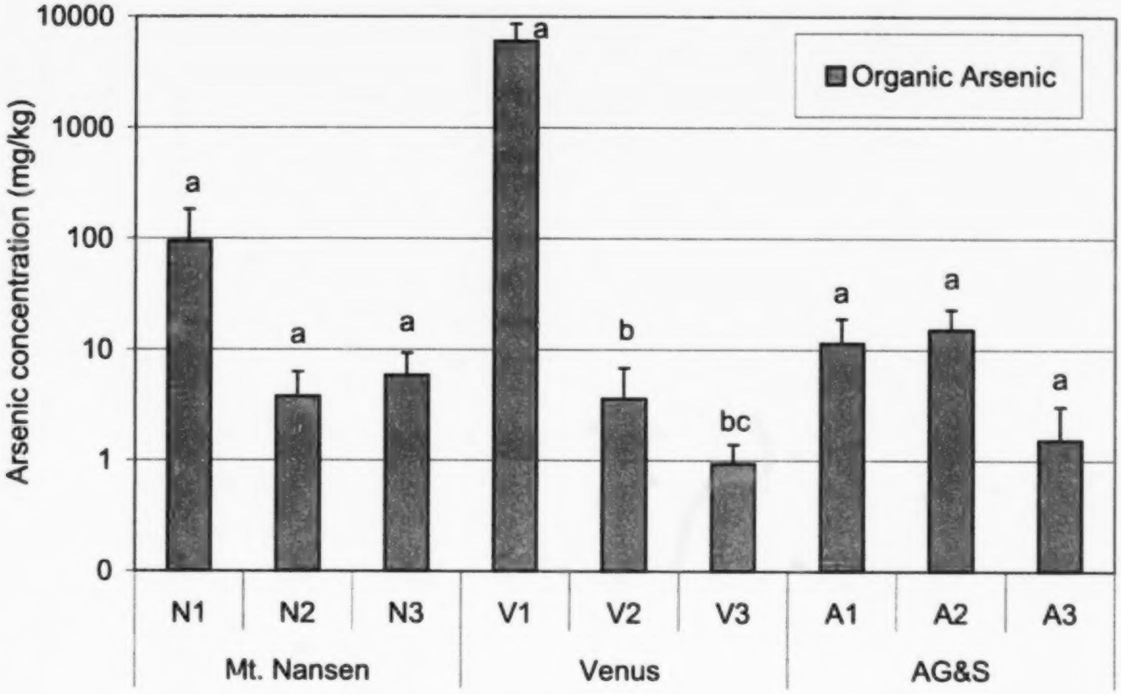

Figure 12. Mean organic arsenic concentration (±SE; dry weight) in soils collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Means with the same letter within a species are not different (p=0.05).

Caribou moss (*Cladina/Cetraria* spp.)

Caribou moss (lichen) yielded the highest arsenic concentrations of all plant species. Arsenic was detectable in all samples, ranging from 0.2 ppm (background sample from a north facing slope of a hill north of Round Lake) to 96.5 ppm (N1 sample collected ~0.75 m from the south edge of the tailings pond). There was significant variation among the three locations (ANOVA p<0.05), and Tukey-Kramer's HSD test showed that the means for locations N1 and N3 were significantly different for all arsenic forms. N2 and N3 were also significantly different for total and inorganic arsenic (Figures 7 and 14).

Cranberries (*Vaccinium vitis-idaea*)

Of the 23 cranberry samples, 19 had less than the 0.05 ppm detection limit. The highest arsenic concentration was 0.5 ppm, from two samples collected from N2 sites. The first was sampled ~1 km west of the tailings pond and ~150 south of Dome Creek on the edge of an old road. The second was collected ~20 m west of the lower old tailings pond and ~40 m NE of Dome Creek. The remaining sample with detectable arsenic (0.3 ppm) came from a site located directly below the upper old tailings pond.

Non-parametric ANOVA on the total, organic, and inorganic data revealed no significant differences between the means of N1, N2, and N3, (Figures 7, 11, and 14).

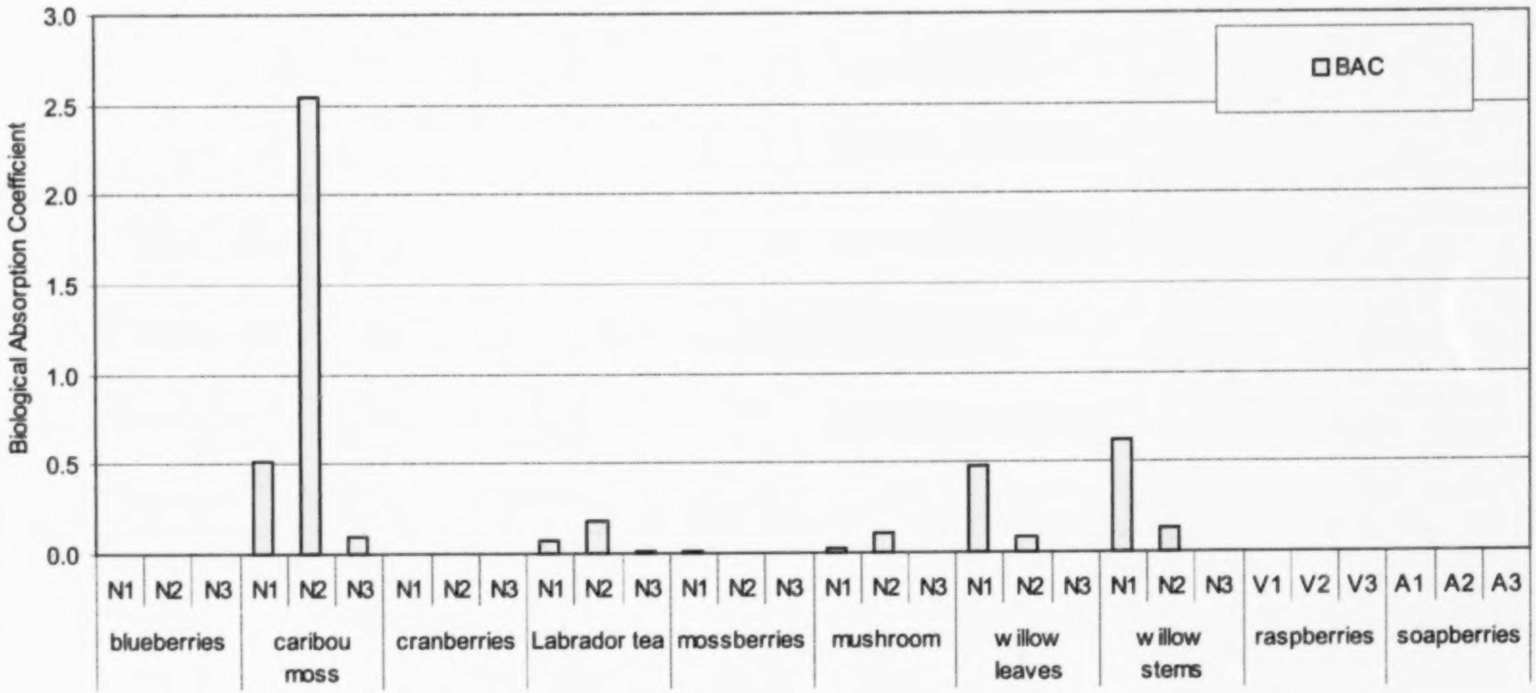

Figure 13. Biological Absorption Coefficient (BAC) for species at different locations within the three mine study sites. BAC is a ratio between plant and soil total arsenic concentrations (mg/kg dry weight).

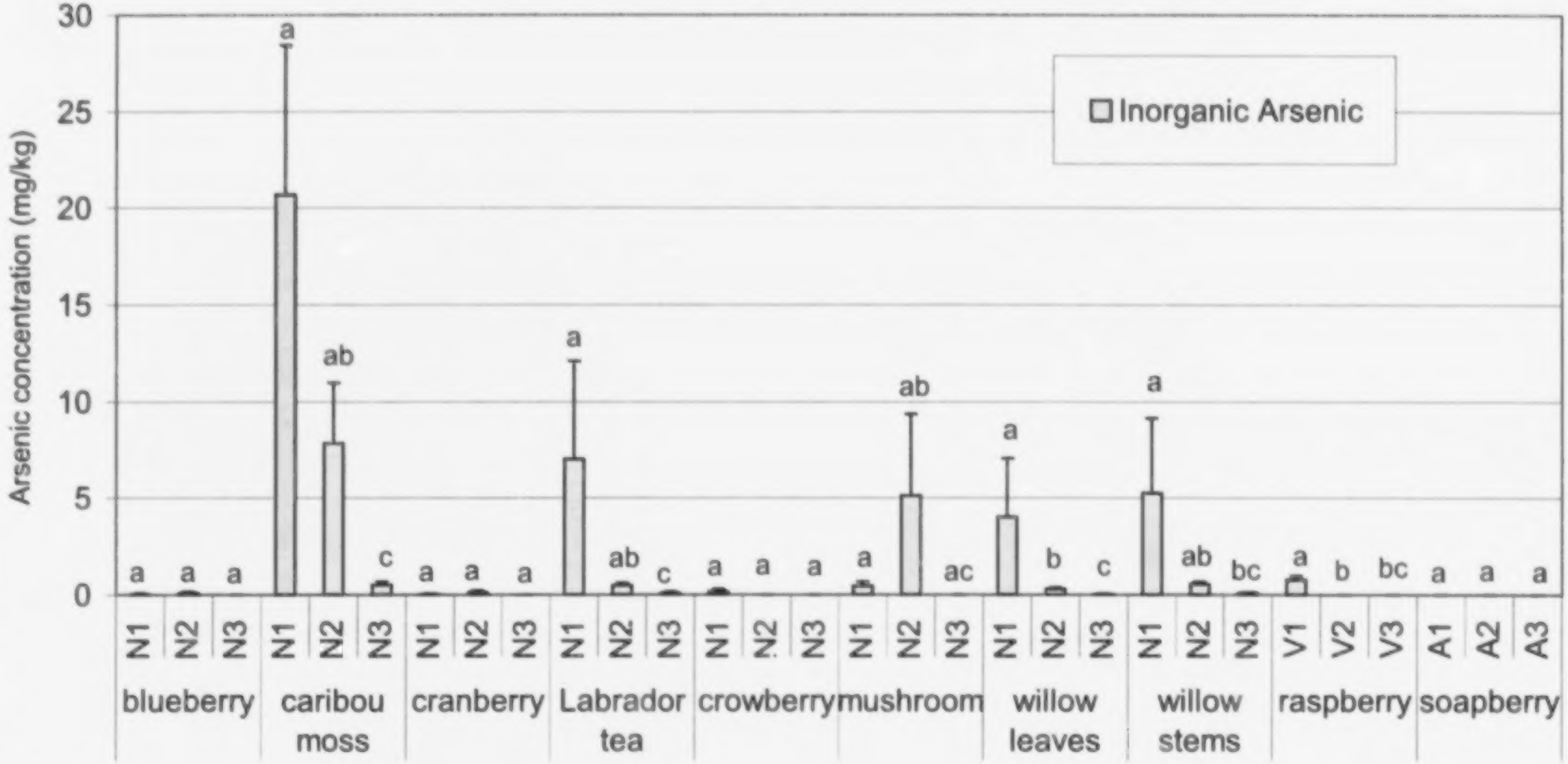

Figure 14. Mean inorganic arsenic concentration (±SE; dry weight) in plants collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Means with the same letter within a species are not different (*p*=0.05).

Labrador Tea (*Ledum groenlandicum/L. decumbens* spp.)

The variance of Labrador tea arsenic data was high: samples ranged from an undetectable background sample collected on the east side of Back Creek (several hundred meters from the Pony Creek confluence) to an 87.8 ppm sample collected 1.5 m from the south-east edge of the tailings pond. The next highest sample was 5.8 ppm from a site on the south edge of Pony Creek, west of the waste rock pile near the adit.

There was significant variation among the sites (ANOVA $p<0.05$) for all forms of arsenic. The Tukey-Kramer HSD test on the transformed total and inorganic arsenic data showed significant differences between N1-N3, and N2-N3 (Figures 7 and 14). For organic arsenic, Dunn's test of the original data did not show any significant differences between locations. However, Tukey-Kramer's HSD test on the ranked organic data showed that N1 and N3 were significantly different (Figure 11).

Mossberries (*Empetrum nigrum*)

Of the 22 crowberry samples, 19 had less than detectable arsenic. The two highest total arsenic concentrations (0.7 ppm and 0.5 ppm) were found near the Brown-McDade open pit: the first is a sample collected from a west-facing slope ~30 m east of the pit, and the other collected 10 m from Pony Creek and west of the adit located there. It is interesting to note that a 0.4 ppm sample, unusually all organic arsenic, was collected from the east-facing slope above the road north of Round Lake. There were no significant differences between the means in the ANOVAs (Figures 7, 11, and 14).

Bolete Mushrooms (*Leccinum* spp.)

Twelve of twenty-one mushroom stem samples had undetectable arsenic, including some collected around point sources. The highest concentration (34.8 ppm) was found in a sample collected beside an E-W oriented access road ~1.5 km north east of the tailings pond, and <1 km west of the open pit and waste rock pile. The next highest sample was 2.6 ppm from a location ~50 m east of the lower old tailings pond and beside a stream (~1 km northwest of the new tailings pond). Non-parametric ANOVA was significant for total and inorganic arsenic data. Both the non-parametric Dunn's test (original data) and Tukey-Kramer's HSD test (ranked data) revealed significant differences in the means between locations N2 and N3 for total and inorganic arsenic (Figures 7 and 14).

Willow Stems (*Salix* spp.)

Willow stems ranged from undetectable to 28.6 ppm (on a hill east of the pit). The next highest concentration was 2.2 ppm (east of the adit near Pony Creek). Willow stem data responded to a log transformation except for organic arsenic data, which required being ranked in order to run parametric tests.

There was significant variation among the locations (ANOVA $p<0.05$) for the total and inorganic arsenic data. At $p<0.10$, ANOVA was significant for organic arsenic data. For all arsenic forms, the Tukey-Kramer HSD test showed significant differences between the means of N1 and N3 (Figures 7, 11, and 14).

Willow Leaves (*Salix* spp.)

Concentrations ranged from undetectable to 22.1 ppm (on the hill east of the pit). The second highest concentration was 2.2 ppm (east of the adit). All three original data sets were not normally distributed. Non-parametric ANOVA showed there were differences among the locations. Both the non-parametric Dunn's (original data) and the Tukey-Kramer HSD test (ranked data) showed significant differences between means for N1-N2 and N1-N3 for both total and inorganic arsenic (Figures 7 and 14). The Tukey-Kramer's HSD test also showed N2 and N3 were significantly different for inorganic arsenic (Figure 14). In a separate analysis of arsenic found in stems versus leaves, mean concentrations were not significantly different from one another between locations (Appendix 3).

Soil

Soil data ranged from 0.8 ppm (N2) to 3083 ppm (N1). Two samples exceeded Yukon CSR guideline, the second value being 2320 ppm (N1). Soil sample means between the locations were not significantly different for total, organic, and inorganic arsenic (Figures 8, 12, and 15).

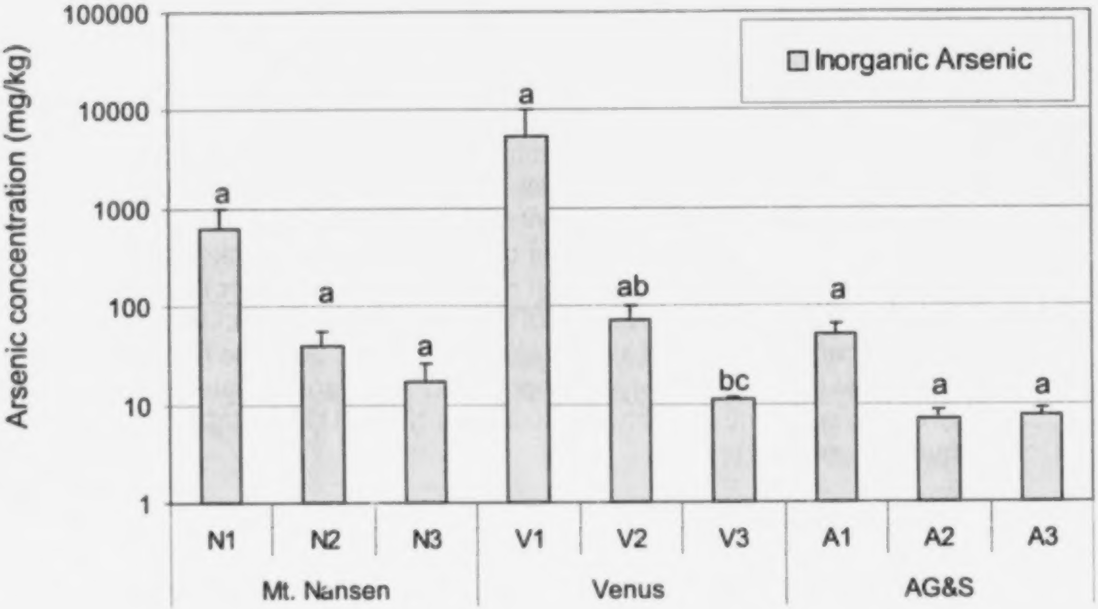

Figure 15. Mean inorganic arsenic concentration (±SE; dry weight) in soils collected at each mine site. Sampling classification as 1 (around point source), 2 (ca. 1-3 km away), or 3 (background). Means with the same letter within a species are not different (*p*=0.05).

4.2 Venus Mine Site

Raspberries (*Rubus acaulis*)

Of the twelve raspberry samples collected from the vicinity of the tailings pond, the gravel pit, and alongside the highway near Carcross, the only samples with detectable arsenic were those found around the capped tailings pond. Total arsenic concentrations of these four samples ranged from 0.4 ppm to 2.9 ppm, with an average of 1.25 ppm (Figure 7). Inorganic arsenic content ranged from 0.4 ppm to 1.2 ppm, with a mean of 0.775 ppm (Figure 14). ANOVA was significant for total and inorganic arsenic data. Dunn's test (original data) and the Tukey-Kramer's HSD test (on ranked data) showed that locations V1-V2 and V1-V3 were significantly different for both of these forms of arsenic (Figures 7 and 14).

Soil

Soil arsenic concentrations at the Venus tailings site ranged from 11.5 ppm (V3) to 23,970 ppm (V1), and three of the nine samples exceeded the Yukon CSR. The two highest soil arsenic concentrations were collected from the same general areas where the two highest raspberry concentrations were sampled: the highest found ~2 m from a stream located at the south end of the cap, and the second highest (9040 ppm) was collected along the NE edge of the cap. The third V1 sample was 1109 ppm. ANOVA showed that there were differences among the locations sampled. Using Tukey-Kramer's HSD test, V1 was different from both V2 and V3 (Figure 8, 12, and 15).
4.3 Arctic Gold and Silver Mine Site

4.3 Arctic Gold and Silver Mine

Soapberries (*Shepherdia anadensis*)

All nine soapberry samples had undetectable arsenic levels.

Soil

Soil concentrations from the Arctic Gold and Silver site ranged from 4.9 (A3) to 83.2 ppm (an A1 sample site located on a vegetated mound in the east centre of the capped tailings). The mean total arsenic concentration for A1 samples collected around the tailings (50.5 ppm) did not exceed the 150 ppm Yukon CSR standard, and these concentrations were quite consistent. ANOVA was significant for inorganic arsenic but subsequent parametric tests showed no significant differences among the means.

Chapter 5: Discussion

The results indicate that for some species there is a spatial trend of lower arsenic concentrations further away from point sources. When compared to data from previous studies, other spatial and temporal trends become apparent as well. These results can be interpreted in terms of individual species response, possible explanatory factors, specific plant uses (as conveyed by First Nation interview participants), and guideline comparisons. For species with detectable inorganic arsenic, a calculation of Tolerable Daily Intakes was warranted for the Carmacks and Carcross residents interested in gathering at the mine sites. These issues will be examined in the following chapter.

5.1 Comparisons With Other Yukon Data

The overall lack of detectable arsenic in the berries collected from Mt. Nansen, Arctic Gold and Silver, and background locations for the Venus Mine tailings property is comparable to arsenic concentrations in the same berries sampled at other Yukon sites such as the communities of Dawson City, Haines Junction, Ross River, Teslin, Watson Lake, and Whitehorse (Gamberg, 2000). Refer to Appendix 4 for specific results.

For Mt. Nansen species with consistently detectable arsenic such as caribou moss and willow twigs, the low concentrations found in the background samples (N3) were representative of the data collected by Gamberg (2000) in Dawson City, Ross River, and Watson Lake[4] (Appendix 4). This similarity was observed with the mushroom data as well, although it is noted that only one sample (from Whitehorse) was identified as a Bolete mushroom (Appendix 4). Its comparison is challenged by the difference in parts analysed (thallus comprised of cap and stem versus stem), particularly if mushrooms store arsenic in different areas as other species do.

5.2 Temporal Trends

Arsenic content in the 2001 Mt. Nansen berries was also comparable to the 1984 Mt. Nansen results found by Godin and Osler (1985). Attempts were made to sample in the same vicinity as their 1984 study (location N4 in Figure 5; analysed as location N2).

During the 1984 study by Godin and Osler (1995), Mt. Nansen surface and depth soil samples were collected from locations around the old tailing ponds. Depth samples (up to 0.5 m) generally had low total arsenic concentrations that ranged between 10 and 180 ppm. One exception was a 28,000 ppm sample collected from the embankment separating the two ponds, at approximately 40 cm depth. The 1984 surface samples ranged from <5 ppm to 300 ppm. Excluding 1984 data from locations not replicated in the 2001 study (location N4), and excluding samples collected in 1984 at depths greater than 10 cm (the maximum 2001 depth), a comparison of total arsenic data from the two studies shows similar results: 1984 concentrations in surface samples range from 70 to 150 ppm; 1984 concentrations in 10 cm depth samples range from 30 to 60 ppm; and 2001 concentrations range from 4.1 to 112 ppm (Figure 16).

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[4] Small sample size (typically n=1) in previous studies affected the ability to determine significant differences and standard error calculations.

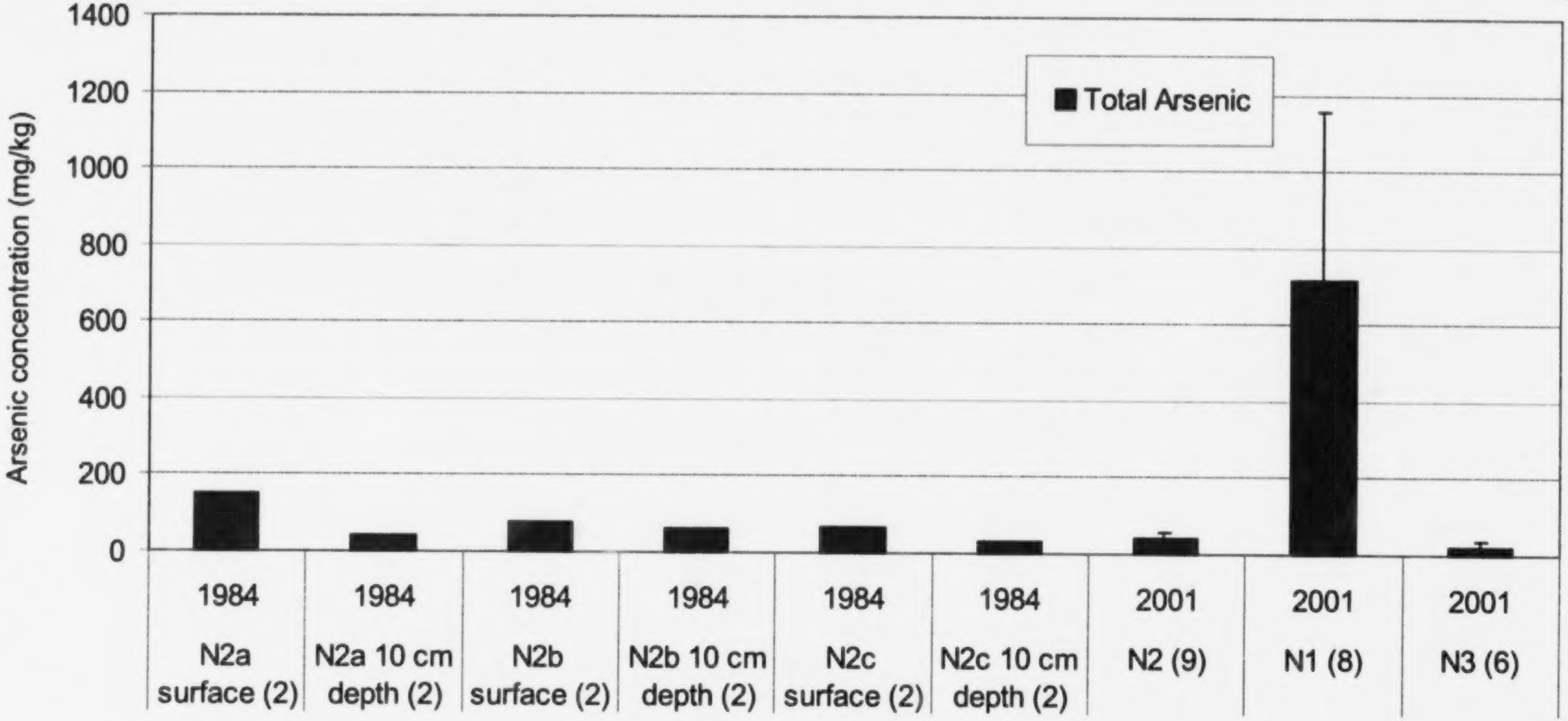

Figure 16. Total arsenic concentrations (±SE; dry weight) in soil samples collected from Mount Nansen in 1984 (Godin and Osler, 1985) and 2001 (this study). Sample size is shown in brackets. Sampling classification as N1 (around point source), N2 (ca. 1-3 km away), or N3 (background). Small-case letters refer to specific 1984 soil sample location: a) embankment of dam separating old tailing ponds; b) seepage site below upper pond; c) below and east of ponds near Dome Creek.

The temporal pattern of arsenic concentrations in raspberries collected near the Venus tailings shows a distinct decrease since the cap was constructed in 1995 (Figure 17).

Soil arsenic concentrations here are also lower than the data collected in an earlier study (Figure 18). In 1984, total arsenic concentrations from surface samples ranged from 45,000 to 83,000, and depth samples (approximately 10 cm) ranged from 800 to 70,000 ppm; there was a distinct decrease in depth for all locations around the tailings pond (Godin and Osler, 1985).

5.3 Interpretation of Results

5.3.1 Mt. Nansen Mine Site

Low or undetectable concentrations in berry samples suggest that if the plant is taking up arsenic, it is not being stored in the fruit. Indeed concentrations are higher in the shoots of other shrubs (Labrador tea and willow). In the sole case where plant parts could be compared, there were no significant differences between arsenic stored in the older woody tissue of the willow stems and the arsenic found in the leaves. This result was unlike the data described in Dunn (1995) where there are clear differences in arsenic concentrations between the stems and twigs versus the roots and outer bark (lodgepole pine), the inner and outer bark (red spruce and paper birch). However, as shown earlier, species have individual responses to arsenic in the environment and cannot be readily compared.

It was difficult to determine whether contamination in Mt. Nansen vegetation was due to mineral extraction or natural sources. Lower concentrations in plants at greater distances from point sources suggest mining activity (predominantly wind-eroded tailings and exposed soil) is a factor, modified by any toxicity-reducing mechanisms used by a species. With background levels being similar to concentrations found in other Yukon plants growing on varied substrates (Appendix 4), bedrock geology appears not to be a strong influence in determining uptake. However, ore is extracted from areas with naturally greater arsenic concentrations, and some ANOVA models indicated that the variation in concentrations could be explained by bedrock geology type (Appendix 3). However, the surficial geology was largely consistent throughout the study site, and believed to be more of a factor for arsenic uptake than bedrock geology.

The results of two species suggest different conclusions as to the origin of the arsenic causing higher concentrations. The BAC for caribou moss suggests these lichens take up arsenic more efficiently than other species. Though lichens contain rhizome-like structures that can absorb elements from their substrate, the general lack of a root system suggests absorption is primarily from airborne sources. Given the lack of exposed rock surfaces in the Nansen region, this points to mining activities such as the presence of trenches, tailings, the open pit, and a waste rock pile as being primary sources of aeolian arsenic. For Bolete mushrooms, the mean for location N2 was skewed by one sample with an arsenic concentration >10 times that of the next highest concentration. This is attributed to natural uptake from the surrounding soil, though it is also possible that soil particles remained on the stalk after rinsing.

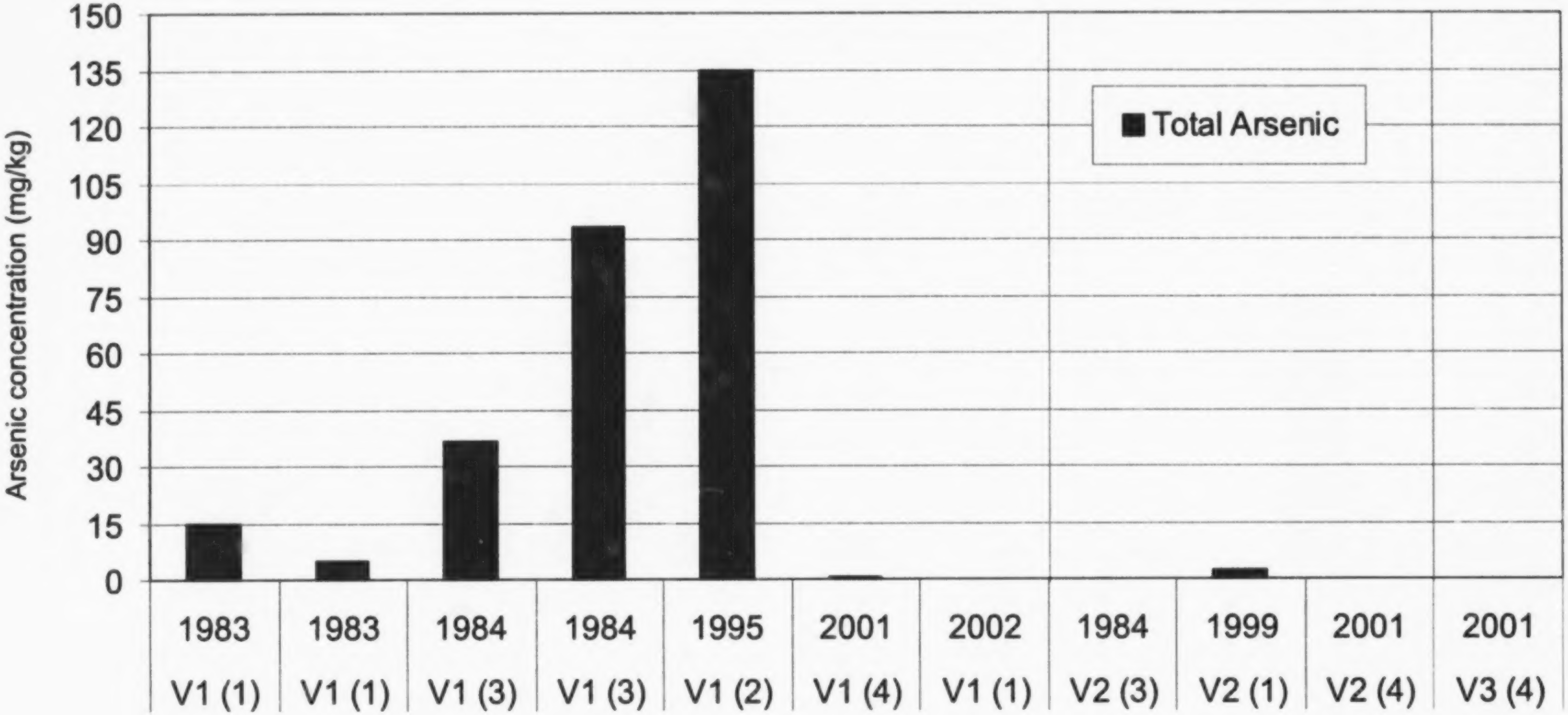

Figure 17. Total arsenic concentrations (wet weight) in raspberry (*Rubus acaulis*) samples collected from the Venus Mine tailings property in different years. Sample size is shown in brackets. Location codes: V1 = tailings site, V2 = gravel pit located ca. 2.25 km north of tailings, V3 =background samples collected off Klondike Highway ca. 17.5 km north of tailings (2 km south of Carcross).

Sources: 1980's data from Godin and Osler (1985); 1995 data from Roach (1995); 1999 data from Roach and Cunningham (2000); 2001 data (this study).

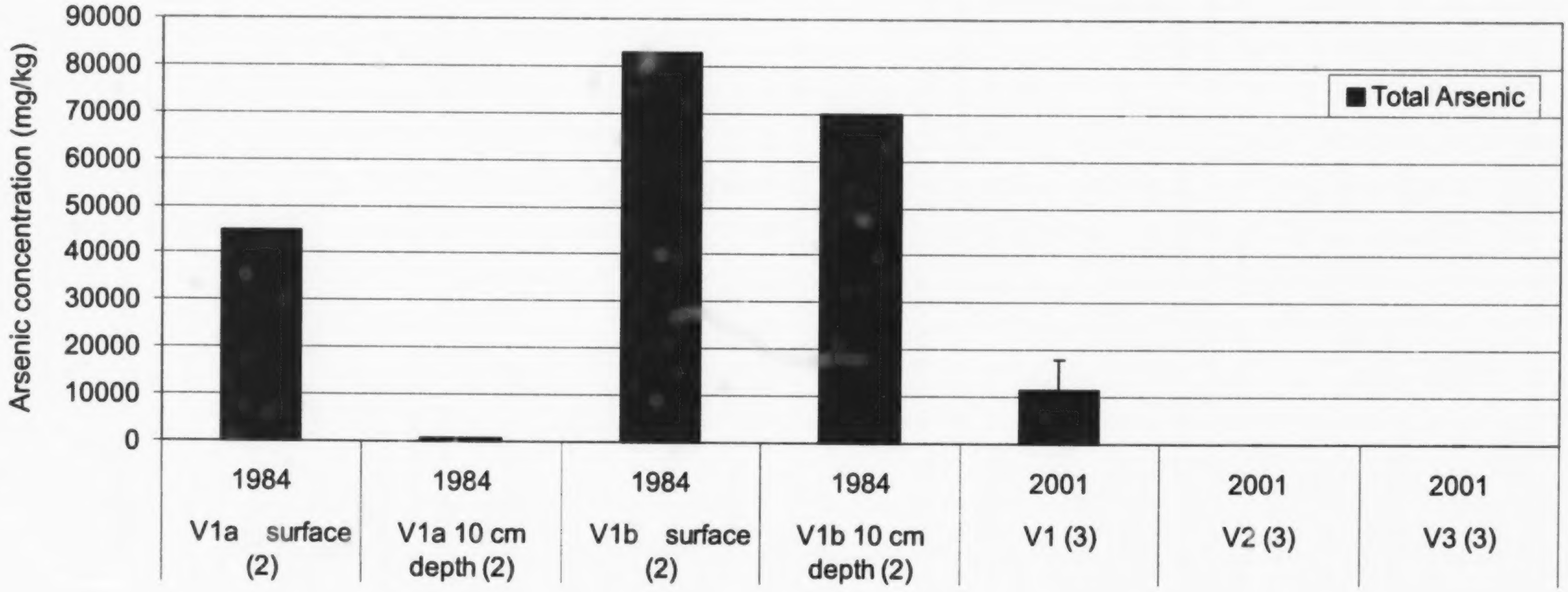

Figure 18. Total arsenic concentrations (±SE; dry weight) in soil samples collected from the Venus Mine tailings site in 1984 (Godin and Osler, 1985) and 2001 (this study). Sample size is shown in brackets. Location codes: V1 = tailings site, V2 = gravel pit located ca. 2.25 km north of tailings, V3 =background samples collected off Klondike Highway ca. 17.5 km north of tailings (2 km south of Carcross). Small-case letters refer to specific 1984 soil sample location: a) SE side of pond near drainage culvert; b) field on north edge of pond (downwind) .

Although some Mt. Nansen soil samples (from N1, N2, and N3) exceeded the CCME guideline of 50 ppm and some N1 samples exceeded the Yukon CSR guideline of 150 ppm, naturally high arsenic content in the soil is suspected to be the major explanation.

It has been suggested that there is a relationship between high Biological Absorption Coefficient values and essential elements (Timperley *et al.*, 1973; Kovalevsky, 1995a). Plotted on a linear scale, the BAC for essential elements (e.g. copper and zinc) decreases as soil concentrations increase, while non-essential elements (e.g. nickel) show a low yet similar concentration regardless of the soil concentration (Kovalevsky, 1995a). The shape of the logarithmic plot created from the 2001 data illustrates the lack of essentiality for arsenic by plants, as do the low BAC values observed during this study (Figure 19). Kovalevsky (1995b) writes that elements in plant ash have BAC values on the order of 300,000, 3000, and 1.0 for plant-gas, plant-water, and plant-soil relationships, respectively. The BAC values for the species in this study are generally lower than the plant-soil ratio.

5.3.2 Venus Mine Site

Arsenic concentrations in raspberry samples have decreased sharply since the tailings pond was capped in 1995. This indicates that the dust problem prior to capping has been minimized.

The decrease in total soil arsenic concentrations between 1984 and 2001 appears to be a result of the 1995 cap construction when (accessible) windblown tailings found in the surrounding landscape were consolidated into the existing pond. The arsenic in these impounded tailings is believed to be immobile, therefore would not be the source of the high concentrations still found in soil samples collected around the Venus tailings. As the levels exceed what would be expected from an arsenic-rich geological substrate, my interpretation is that hot spots exist. The dominant wind direction at the Venus site is from the south; high soil concentrations potentially reflect windblown tailings not collected during the capping project.

5.3.3 Arctic Gold and Silver Mine Site

While other berries (bearberry and raspberry) had detectable inorganic arsenic in the 1999 study at the Arctic Gold and Silver property (Roach and Cunningham, 2000), no pre-reclamation soapberry data exists, so species cannot be compared as such. (Readers are reminded that the 2001 collection was based on berries that were ripe and abundant throughout the entire study site.) The occurrence of windborne tailings is no longer an issue as it may have been during the 1999 study, suggesting that if there was an impact from dust on local soapberries, it has now been minimized.

Arsenic concentrations in soil from the Arctic Gold and Silver property are of low concern. Although the mean concentration of samples collected around the tailings exceeds the territorial background concentration, Montana Mountain bedrock is arsenic-rich, which leads to elevated soil arsenic levels.

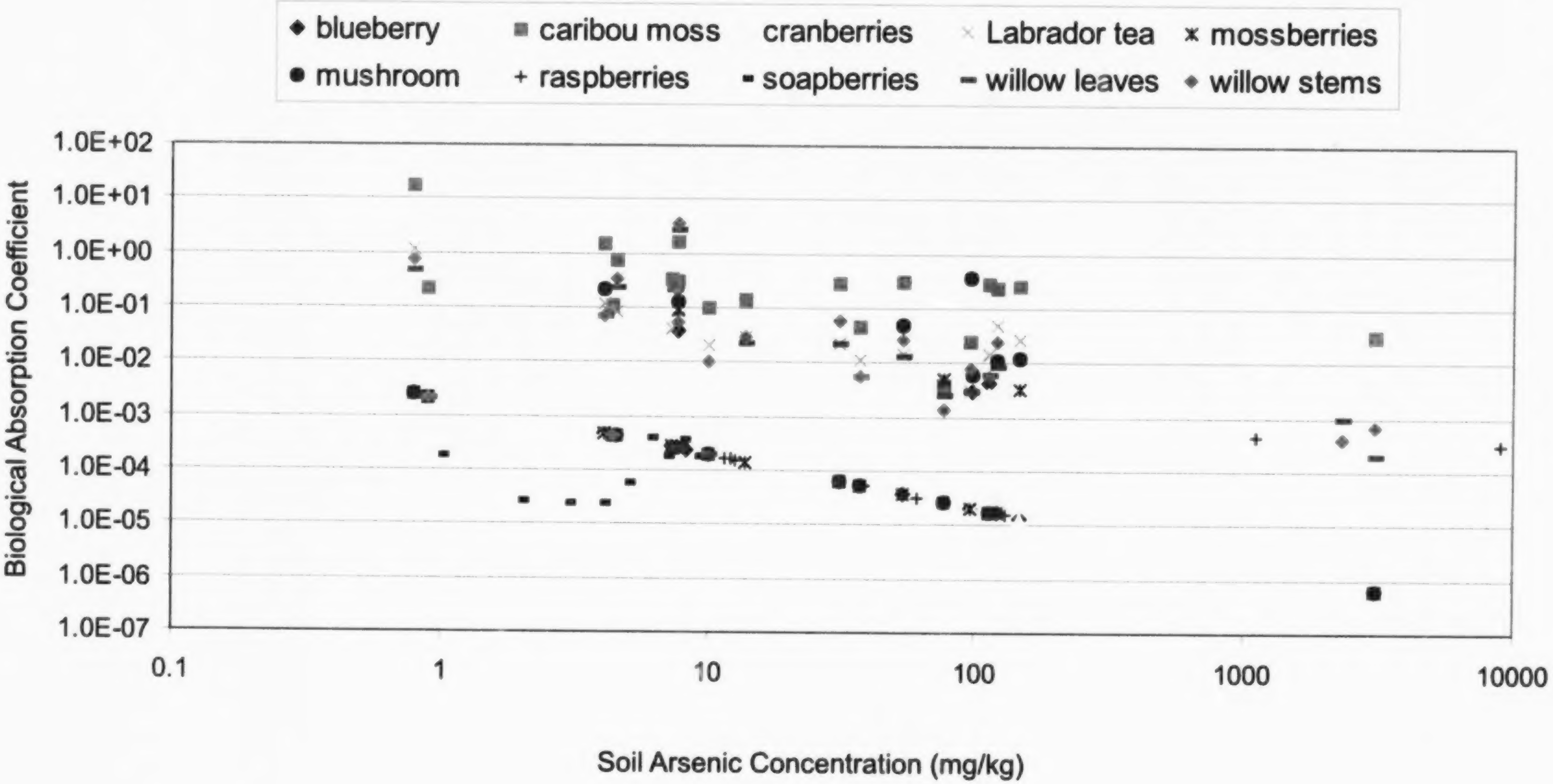

Figure 19. Biological Absorption Coefficient (BAC) plotted against total arsenic soil. Due to the presence of outliers, a logarithmic scale was used for clarity.

5.4 Ethnobotany

Interview comments about the species chosen for analysis in this study are provided in the following section, supplemented by other literature sources. The medicinal properties of a particular plant are often associated with chemicals found within the leaves, roots, stems, or fruit. For this reason, the description for each species includes compounds found within the plant, uses of individual plant parts, general habitat, and any advisories about the plant. A glossary of chemical compounds is located in Appendix 6a. A glossary of selected terms used throughout this dissertation is found in Appendix 6b.

5.4.1 Discussion of Plants Sampled in This Study

Blueberry – food, medicine

The berries contain vitamin C. Blueberry leaves contain tannins, flavonoids, alkaloids, and iridoids (Marles *et al.*, 2000).

Species of blueberries found in the Yukon include the abundant *Vaccinium uliginosum* (bog blue/bilberry), and *V. caespitosum* (dwarf blue/bilberry) and *V. ovalifolium* (oval-leaf blue/huckleberry) which are found only in the south. *V. uliginosum* is typically 20-60 cm tall, and grows in wet acidic areas such as swamps and muskegs, as well as in woodlands, heath, and on alpine slopes (Cody, 2000). *V. caespitosum* grows to ~20 cm, and is found in alpine and subalpine areas while *V. ovalifolium* is 20-100 cm high, and grows on subalpine slopes (Cody, 2000).

Like most berries, blueberries are eaten as raw fruit or "candy", canned, or cooked in muffins or cookies (female elder, pers. comm., 2001).

Eating berries improves acne, while consuming syrup can treat vomiting (Marles *et al.*, 2000). Leaves and roots are both boiled and drunk to treat diarrhea: leaf tea (and dried berries) are also taken for urinary tract infections, and the tea is used by some diabetics to moderate sugar levels (Kershaw, 2000). Stems are boiled and drunk to help prevent pregnancy (Marles *et al.*, 2000) while stems and leaf tea is drunk to improve colds (Andre and Fehr, 2001). Root tea is gargled for sore throats, or used to treat sores (Kershaw, 2000).

Bolete mushroom – food, medicine

Leccinum insigne (aspen scaber stalk), *L. aurantiacum* (orange birch bolete/red-capped scaber stalk), and *L. scabrum* (birch bolete/common scaber stalk) are three members of the Bolete family of mushrooms found in the Yukon. All three can be misidentified due to their similar appearance: *L. insigne* has a reddish to orange-brown cap and grows under aspen or mixed aspen and birch stands, *L. aurantiacum* has an orange-red cap and grows under coniferous and deciduous trees, and *L. scabrum* has a brown cap and is found under birch trees (Lincoff, 1981). All have black scales on white stalks, and under the caps are spongy pores rather than gills (Parker, 1994).

Nutrition information specific to this family was not available, but Kuhnlein and Turner (1991) write that mushrooms generally have high moisture content, few vitamins, and minor levels of carbohydrates, fibre, protein, and lipids. One can get diarrhea from eating too many Bolete mushrooms (K. Charlie, pers. comm., 2001).

Bolete stems are typically eaten and the cap discarded, though the latter is consumed if no maggots are present. Mushrooms are picked whenever it rains. They are then cut up and placed in the freezer or dried - a delicacy for elders. Added to fish soup, fish chowder, or frying onions (female elder, pers. comm., 2001), mushrooms are eaten raw, roasted, or fried. They can also be rolled in the campfire to blacken; the black part is removed and the remainder eaten (V. Johnnie and B.P. Johnnie, pers. comm., 2001). These "orange tops" have been used to make mushroom soup to entice anorexics to eat (female elder, pers. comm., 2001). They are also eaten by moose (K. Charlie, pers. comm., 2001) and bears (D. Charlie, pers. comm., 2001).

Caribou moss (lichen) – animal fodder, medicine, soup thickener

Lichen species comprising "caribou moss" are found in wet and dry coniferous forests (such as Yukon's ubiquitous spruce stands), as well as peatlands. They are fruticose lichens that form clumped mats, often in late snow-melt regions (Andre and Fehr, 2001). Species most commonly identified as reindeer lichen include *Cladina mitis* (yellow), and *Cladina rangiferina* (grey/green), though numerous other *Cladonia* and *Cetraria* have the characteristic branchlets of caribou moss (Vitt *et al.*, 1988).

These lichens contain polysaccharides, proteins, and acids that may cause stomach upsets if not cooked well (Kuhnlein and Turner, 1991). Some people are sensitive to usnic acid, which may result in red, itchy skin (Kershaw, 2000).

Partially digested lichens from the caribou rumen were mixed with a variety of other plants and eaten (Kuhnlein and Turner, 1991). Caribou moss is regularly consumed by grouse, ptarmigan, gopher, caribou, porcupine, and buffalo (M. Roberts and E. Billy, pers. comm., 2001). These lichens are also eaten by bears, birds, mice, and dogs (female elder, pers. comm., 2001). The Tutchone name comes from the "gew" sound made when you walk on dry moss (M. Roberts and E. Billy, pers. comm., 2001).

The thallus is boiled and the fluid drunk for medicinal purposes - *any bad disease can be cured* (female elder, pers. comm., 2001). Drinking either the tea or dried and powdered lichen soaked in water can help treat intestinal worms (Marles *et al.*, 2000). The tea also relieves stomach and chest pains, and is drunk to maintain energy, while lichen itself can be eaten fried, after being boiled twice and strained, or dried and added to soup as a thickener (Andre and Fehr, 2001). Tea made from grey reindeer lichen (*Cladina rangiferina* as opposed to green reindeer lichen, *C. mitis*) is taken for fevers, diarrhea, jaundice, tuberculosis, and convulsions (Kershaw, 2000).

Cranberry – food, medicine

Vaccinium vitis-idaea (lowbush cranberry) is a shrub that resembles *Arctostaphylos uva-ursi* (bearberry/stoneberry/kinnikinnick). They can be differentiated by the small black spots located on the underside of the cranberry leaves (B. Brown, pers. comm., 2001), and by opening up a berry to see if has a seed and the characteristic whitish flesh of a bearberry (Hargrave, 1997). Growing in bogs and other open acidic areas, the shrubs are usually only 5 – 20 cm tall (Cody, 2000).

Lowbush cranberry leaves and berries contain arbutin, a substance that prevents certain bacteria from sticking to bladder and urinary tract walls such that an infection is caused (Kershaw, 2000; Marles *et al.*, 2000). The berries also contain benzoic acid therefore keep well in storage (Willard, 1992). Diarrhea can arise by consuming large amounts of berries (Kershaw, 2000).

Eaten raw, the berries are best picked in autumn after the first frost. Cranberry jam is sometimes made: berries are added to flour and sugar and then boiled (K. Charlie, pers. comm., 2001).

Berries are boiled and the juice is saved (M. Roberts and E. Billy, pers. comm., 2001). Cranberry juice is used for kidney problems, colds, stimulating the appetite, reducing heartburn, and as a dye (Willard, 1992; Andre and Fehr, 2001). A crushed or boiled cranberry mash can be used as a poultice (e.g. for measles rash), and the berries are eaten to improve nausea, sore throats, cramps, childbirth pains, and convulsions (Kershaw, 2000; Viereck, 1987). Cranberry leaf tea is a general tonic (Viereck, 1987). Oily skin and hair can be treated using a rinse (Willard, 1992). A tea made from boiled roots and stems is used for bladder problems (Marles *et al.*, 2000).

Crowberry – food, medicine

Empetrum nigrum (crowberry/mossberry/blackberry) grows in moist, mossy regions on the forest floor, in swamps, heathlands, and on tundra (Cody, 2000). The plants are generally less than 15 cm (Andre and Fehr, 2001).

These black berries are eaten raw, used for jam (W. Atlin, pers. comm., 2001), or fried with grease and placed in a jar with bannock (K. Charlie, pers. comm., 2001). Their flavour is improved if berries are picked after the first frost and by adding other ingredients such as lemon and sugar (Willard, 1992). One can get constipated if too many are eaten (M. Roberts and E. Billy, pers. comm., 2001).

Crowberry shoots are boiled and drunk to alleviate diarrhea, colds, kidney problems, and tuberculosis, while the roots or berries can be boiled and used to treat sore eyes (Viereck, 1987; Willard, 1992). A tea from berries, stems, and roots treats stomach-aches (Andre and Fehr, 2001). Shoots can be chewed or applied to skin to treat fevers (Marles *et al.*, 2000).

Labrador tea - medicine

Ledum groenlandicum (common Labrador tea, also known as *L. palustre* spp. *groenlandicum*) and *L. palustre* (northern/marsh Labrador tea, also known as *L. palustre* spp. *decumbens*) are the two types of Labrador tea found in the Yukon. *L. palustre* is found in dwarf shrub and moss-lichen heaths, and grows to 50 cm, while *L. groenlandicum* is common in peatlands, bogs, and meadow with a typical growth of 30-60 cm (Cody, 2000). Both species have green leaves with fuzzy orange undersides.

Labrador tea contains toxins (ledol), and narcotic compounds (Kershaw, 2000). Leaves contain tannins, flavonoids, volatile oils, and small amounts of poisonous andromedotoxin (Marles *et al*., 2000). It is suggested that this species is not dried in an enclosed space, as high concentrations of volatile oils may affect the heart (Hutchens, 1991). There are a number of reactions that can occur from consuming large doses of this species. They include headaches, vomiting, increased drowsiness and urination, cramps, delirium, heart palpitations, temporary paralysis, and death (Kershaw, 2000; Marles *et al*., 2000). For this reason, Kuhnlein and Turner (1991) recommend that the plant be consumed infrequently, and in dilute tea form. There is conflicting information about whether or not to boil the shoots for long periods; alkaloids may be destroyed, but ledol is released (Kershaw, 2000).

Labrador tea is drunk daily as a tonic, and has many more medicinal uses than mentioned below. Shoots are boiled, stored in a jar in the fridge, and drunk as a tea served hot or cold (K. Charlie, pers. comm., 2001). The liquid is good for heart attacks and the stomach (V. Johnnie and B.P. Johnnie, pers. comm., 2001), chest pain, bad colds, and for a face wash (to improve acne) (female elder, pers. comm., 2001). Marles *et al*. (2000) mentions that leaves have been put on wounds, chewed to treat flu, diarrhea, and bad breath, and powdered to treat burns. Despite treating diarrhea, Labrador tea is a slight laxative (Viereck, 1987). A female elder (pers. comm., 2001) said it makes one relax when one is depressed, and called it a "sleeping pill, though the flowers are no good; just the leaves are used". The tea can also treat alcoholism: shrubs are picked, boiled for 1 hour, put in a jar, and drunk tea four to five times per day – "no alcohol from then on" (V. Johnnie and B.P. Johnnie, pers. comm., 2001). Labrador tea can wash out lice, treat insect bites, and repel insects (Willard, 1992).

Raspberry – food, medicine

Rubus arcticus ssp. *acaulis* (dwarf raspberry/nagoonberry) and *Rubus idaeus* (wild red raspberry/tall raspberry) are common in the Yukon. The former is a low-growing shrub (< 15 cm) that is found in shaded wooded regions surrounding lakes (Andre and Fehr, 2001). *R. idaeus* is found in disturbed sites such as alongside roads, and open woodland clearings - they are usually less than 1.5 m high (Cody, 2000).

Raspberry leaves contain fragarine, which acts to both relax and stimulate the uterus wall muscles (Kershaw, 2000). Leaves also contain tannins, flavonoids and vitamin C (Marles *et al*., 2000). The berries are mildly laxative (Willard, 1992).

Berries are eaten raw, and used for making raspberry jams and jellies. Flowers can be added to salads, and peeled shoots are also consumed (Willard, 1992).

Berries are good for nerves, while roots can be powdered to make into a tea for arthritis (I. Calmegane, pers. comm., 2001). Leaves and stalks are used for treating burns (K. Charlie, pers. comm., 2001). Raspberry stems and roots are boiled and drunk to treat diarrhea and fevers, gargled for sore throats, or used as an astringent/wash for wounds (Viereck, 1987; Marles *et al*., 2000). Raspberry leaf tea is also given to pregnant women for nausea and menstruating women who have cramps or high flows (Willard, 1992; Kershaw, 2000).

Soapberry – food, medicine, soap

Shepherdia canadensis (soapberry/soopolallie) is a shrub with bright red berries dotted with gold. It usually grows 1-2 m in the south (60 cm further north), and is found in open dry spruce stands, along rivers, and on alpine slopes (Cody, 2000; Andre and Fehr, 2001).

Kershaw (2000) mentions the berries are a source of vitamin C and iron, although this is not indicated in nutrient tables listed in either Kuhnlein and Turner (1991) or Medical Services Branch (1994). The berries also contain saponin; consuming too many berries can cause diarrhea, vomiting, and cramps as this detergent-like substance irritates the stomach (Kershaw, 2000; Marles *et al.*, 2000).

Their bitter flavour is improved if berries are picked after the first frost (Willard, 1992) and by adding other ingredients. When combined with sugar and water and whipped, a frothy "ice cream" dessert is created. W. Atlin (pers. comm., 2001) mentions a typical ratio might be a "heaping tablespoon of berries, 4 tablespoons of water, and 1 tablespoon of sugar", and warns that the "mixture will not rise if there is any butter or oil on the beater or bowl". In Tlingit culture, soapberries were the most celebrated type of berries produced at a feast, and the whipped dessert was served last (Thornton, 1999). Soapberries are most popular eaten as ice cream (K. Charlie, pers. comm., 2001; female elder, pers. comm., 2001). They are also eaten with bannock (female elder, pers. comm., 2001), and by mixing with grease and salmon eggs (V. Johnnie and B.P. Johnnie, pers. comm., 2001; female elder, pers. comm., 2001).

Boiled juice is good for ulcers (M. Roberts and E. Billy, pers. comm., 2001; K. Charlie, pers. comm., 2001; female elder, pers. comm., 2001), for washing out the stomach (M. Roberts and E. Billy, pers. comm., 2001), and for constipation (Kershaw, 2000). A mixture of soapberry juice, sugar and water is used for acne, boils, digestion problems, and gallstones (Turner, 1997). Stems are boiled and drunk for a laxative (Kershaw, 2000). The tea also can help prevent miscarriages, treat tuberculosis and venereal disease, or be used as a wash for cuts and swellings (Marles *et al.*, 2000). Bark tea aids problems with eyes (Kershaw, 2000). A tea made from stems and roots is said to relieve stomach pains and diarrhea, while raw berries or berry tea is recommended for colds or sore throats (Andre and Fehr, 2001). Berries can improve flu and indigestion conditions; crushed or boiled, the raw berries can also be used as soap (Kershaw, 2000). The berries were mentioned as a good medicine; a diabetic woman ate them and her blood sugar was level for a week (W. Atlin, pers. comm., 2001).

Willow – medicine, tools, animal fodder, and fuel

Salix species are common in Yukon's wet muskeg areas, on floodplains and alongside creeks, and in well-drained open birch, aspen, and spruce stands (Cody, 2000). They range from prostrate growth to up to 7 m tall (Andre and Fehr, 2001). There are 34 known species of *Salix* in the Yukon; the most abundant of which include *S. arbusculoides*, *S. arctica* (dwarf willow), *S. glauca* (blue-green willow), *S. myrtillifolia*, *S. planifolia*, and *S. reticulata* (net-veined willow) (Cody, 2000).

Willow bark contains flavonoids, tannins, aldehydes, and salicylates such as salicin (Marles *et al.*, 2000). Some parts of willow have high ascorbic acid content (Kuhnlein and Turner, 1991).

Young shoots of this shrub are food for moose, caribou, and some horses (female elder, pers. comm., 2001). Grouse, ptarmigan and moose eat the soft parts of willow (M. Roberts and E. Billy, pers. comm., 2001), while bears eat pussy willows and beavers eat the bark (W. Atlin, pers. comm., 2001). Moose eat twigs in wintertime (K. Charlie, pers. comm., 2001).

Willow branches and roots provide shelter, fuel, and multiple tools. Willow is used for making baskets, dream catchers, picture frames, cradles for babies, and frames for babies' faces so they are not smothered while sleeping; the frames are also placed over the mouth to avoid mosquitoes or germs (female elder, pers. comm., 2001). Other willow uses include snowshoes, smokehouses, sweat lodge frames, canoes, nets, rope, and mats (Marles *et al.*, 2000; Andre and Fehr, 2001).

Willow is used for medicinal purposes (I. Calmegane, pers. comm., 2001) and is collected in spring and fall (female elder, pers. comm., 2001). Used as a substitute for aspirin, willow is a pain remedy for headaches (female elder, pers. comm., 2001; I. Calmegane, pers. comm., 2001), and is also good for osteoporosis, and arthritis (female elder, pers. comm., 2001). The bark is peeled off, boiled, and the liquid drunk, though the stem can also be cut off and sucked (female elder, pers. comm., 2001). Willow can help bee stings: leaves are chewed, balled up and placed on stung area (V. Johnnie and B.P. Johnnie, pers. comm., 2001).

Willow leaf tea can be used as a wash for skin infections and willow bark tea is drunk to relieve diarrhea, digestion, rheumatism, and urinary tract infections (Kershaw, 2000). Crushed leaves or peeled roots can treat rashes, cuts, ulcers, and toothaches (Marles *et al.*, 2000; Andre and Fehr, 2001). Kershaw (2000) mentions these conditions (along with ulcers, corns, and cancers) that are improved using bark tea or bark strips. A poultice of powdered bark in cream can be applied externally to treat gangrene (Hutchens, 1991). Tea made from the root helps treat internal bleeding, throat constriction, and venereal disease (Willard, 1992).

5.4.2 Preparation of Plant Medicine

First Nation people (usually older women) follow specific steps for harvesting medicines that have been passed down through generations. The steps have spiritual connections, as shown below in the list of suggestions mentioned by Ida Calmegane (pers. comm., 2001).

- It is important to always give a gift – my grandma said it doesn't matter what, as long as it is important to you. Beads and silk and tobacco are examples. Tobacco is mostly still used.
- Say prayers before you ever pick medicines. If you're picking medicine for someone else, you say who you are picking medicine for, and ask the spirits to help you and ask blessings.

- Always pick from plenty – never pick from any place that doesn't have many. Leave some behind.
- Have a little on hand. Never stockpile it. It's good to pick it fresh.
- Most of plants can be picked just about anytime. Plants growing on the ground - I like to get in summer months. Picking usually based on someone needing it.
- For women, it's really important that you're not on moon time [menstruation] when picking medicines, as women have ability to give life and at that time, you're very strong. Medicines picked at that time goes into you and are not patient. [This is] taboo to do in our culture. [This isn't an issue when you] become an elder and no longer have moon times.

Clearly harvesting dates for berries and other seasonal plant parts coincide with the time of year when the plant is ripe and at its peak. This differs according to shifts in seasonal climate and micro-site conditions, but the following timeframe suits the southern Yukon: currents and strawberries appear in early summer (late June), blueberries, raspberries, and Saskatoon berries are usually picked mid to late summer, and cranberries, mossberries, and rose hips tend to be harvested after the first frost in September (Hargrave, 1997).

Careful steps are also followed when preparing medicine. This is revealed in the following description by I. Calmegane (pers. comm., 2001) for preparing tea from the bark of a medicinal tree species such as red alder, balsam fir, or Jack Pine.

> Pick bark from the north side of the plant because the sun is too hot on the morning side (east). Take a sharp knife and peel 2-3 slices off tree (18" x 2" wide) – then you know you don't kill the tree and that it is there for you to use again some other time. Put them in an enamel or Pyrex pot. Put a gallon and a half of water in. Once it comes to full boil, turn the heat down and boil gently for 25-35 min (no longer). Strain as soon as it cools off. Take all of the water out and store it cold. [The medicine is ready to be drunk. If the receiver of the medicine is still sick after one week], next week, put 1 branch [slice] in. Lay under bush when [the medicine is no longer needed] and say prayers. Or use a good burning barrel. Never put it in garbage and destroy it like that.

W. Atlin had this advice for knowing when to take and when to stop taking medicine: take a teaspoon first to see if [the medicine] agrees with you. If you take it against your will, it's not going to help you… your body craves it and when it doesn't crave it anymore, that's when it's enough. She also pointed out the importance of picking and preparing medicine well: if you don't treat medicine right, it goes away and doesn't grow there anymore… medicines have to be nice and clean – no dirt… use the same pot (W. Atlin, pers. comm., 2001).

Family members and local Elders taught many of those interviewed about medicines at an early age. Some continue to prepare only the medicines passed down to them; while others communicate with knowledgeable people in other communities to exchange ideas, and occasionally consult published literature.

5.5 Tolerable Daily Intake Calculations

Tolerable daily intake (TDI) values were calculated from inorganic arsenic data taken from each of the three locations at the Venus and Mt. Nansen mining properties, for all species with detectable arsenic (Appendix 5). Given the variance in the data, TDI's have been provided for the mean concentration found at a particular location, and for the samples with the highest and lowest concentrations. TDI's are separated by age group using Health Canada age and body weight standards, and are reported in grams/day in terms of wet weight (as berries would be picked and eaten raw) as well as dry weight (useful for comparative purposes as moisture content is no longer a factor). These are suggested values only, based on the size of the sample population collected at each location (n=3 to 9).

Since consumption patterns change annually based on the production success of each season, residents can individually determine how much they are consuming of a particular food, and decide berry and mushroom picking locations accordingly.

5.5.1 Mt. Nansen Mine Site

The high variability in concentrations of mushrooms (and consequent TDI calculations) suggests residents pick from the Mt. Nansen region with caution. There was no apparent spatial pattern with this species, but samples apparently had less arsenic when collected from areas where the ground was not disturbed. Risk to foragers is likely low as Bolete mushrooms are not the primary food source for any wildlife species.

The health risk from Labrador tea is difficult to determine since the shoots are boiled for tea, rather than directly ingested. The TDI grams/day values are conservative estimates as they are based on the assumption that the entire shoot is consumed. It is unknown how much arsenic is released from the plant during boiling.

The TDI's for willow leaves are also conservative estimates, given that the leaves are chewed but not ingested when used medicinally. Moose and other wildlife consume willow shoots but insufficient information is available about the foraging habits of these animals in order to assess the health risk of consuming willow stems by foragers at Mt. Nansen.

Likewise, insufficient information was available in order to calculate a risk-based assessment of the lichen-caribou-human food chain. This may be a low priority since caribou tend to stay in valleys west of Mt. Nansen and likely do not ingest any appreciable amount of arsenic-rich lichen.

The concentration of arsenic in berries fell well below any need to calculate a TDI. Cranberries, mossberries, and blueberries should be considered safe to eat by Carmacks residents, according to the results from all areas sampled in 2001.

5.5.2 Venus Mine Site

The TDI's for raspberries at the Venus Mine tailings site (V1) are encouraging, given the history of high arsenic contamination here. Adults can safely consume 811.6 g/d, while young babies can safely eat 81.2 g/d (Appendix 5). Since arsenic is still detectable in raspberries, it is suggested that residents consider picking berries here, but to use the TDI's with the knowledge that the mean is based on only four samples collected around the capped tailings.

5.5.3 Arctic Gold and Silver Mine Site

TDI's could not be calculated for soapberries at the Arctic Gold and Silver property since they had undetectable arsenic.

Chapter 6: Recommendations and Conclusions

6.1 Recommendations

Based on the results of this study, several site-specific recommendations can be made (beyond those suggested earlier with regards to the choice of gathering locations).

6.1.1 Mt. Nansen Mine Site

The first recommendation is to monitor water at Pony Creek downstream of waste rock as "existing ore dump from previous mining of the sulphide ore from the Brown-McDade zone which is located in the Pony Creek drainage... is currently a source of contamination to Pony Creek" (T.W. Higgs Associates, 1995, p. 51). This ore dump was to have been either re-processed or transported to the tailings pond by B.Y.G. Resources Inc, prior to their mine reclamation. According to T.W. Higgs Associates (1995), this should be a priority activity.

Thoroughly rinsing shrubs that are used medicinally prior to use is also recommended, as windborne dust is suspected to have been the reason for samples with the highest arsenic concentrations in willow and Labrador tea. However, residents will not likely gather from the Mt. Nansen property itself until mine reclamation has been completed, and certainly berries and shrubs collected in this study are available in other areas.

A dust-monitoring program examining arsenic in wet and dry particulate deposition would be useful for determining the source of this element.

If pond water is low and the tailings exposed, it may be prudent to erect a temporary fence around the perimeter for collecting windborne tailings, and to prevent foragers from wading through or drinking the water. This is likely not possible around other structures (e.g. Brown-McDade open pit), though a reclamation program should re-seed bare ground to prevent erosion.

The suggestion to construct a fence around the pond and to place a net over it to discourage waterfowl was given to DIAND in 2000, which responded with the following comments:

> I think there are measures which are more practical, effective and less costly. To build a fence, the posts would have to be placed in permafrost or unconsolidated material and would not remain upright. An electric fence on surface tripods would be ineffective in keeping large mammals out of the tailings area and would pose a risk to the DIAND-contracted work force. Given the substantially reduced cyanide levels now in the tailings pond, there is little danger to wildlife. With the onset of winter, the pond and saturated tailings are frozen, so there is almost no possibility of mammals being trapped in soft material. The waterfowl is gone for the year. Even during the summer there are people moving around the site constantly, so large mammals do not frequent the site. DIAND's approach of reducing the cyanide concentrations in the pond and the water levels as much as possible is the best and most cost

effective solution to the concerns of contamination of the tailings pond water (P.H. Beaubier, pers. comm., 2000).

Based on the higher arsenic concentrations in caribou moss, Carmacks residents may consider monitoring the movement of caribou in the region, particularly around the tailings pond, and study their arsenic concentrations if necessary.

The last recommendation for this property is to maintain sampling of vegetation so as to monitor temporal trends. Species that were collected but not analysed in the 2001 study include red moss (*Sphagnum* spp.), puffball mushrooms (*Lycoperdon* spp.), cloudberry (*Rubus chamaemorus*), red bearberry (*Arctostaphylos rubra*), caribou horn (*Cornicularia aculeata*), and grey caribou moss (*Cladina rangiferina*). Most are not full collections (between 1 and 25 samples), but they remain in frozen storage at UBC and are available for analysis should the need arise, and should funds become available.

6.1.2 Venus Mine Site

Based on the arsenic found in the sole plant species (raspberries) analysed at this site, high soil concentrations do not appear to be a concern. Local residents can consider picking berries here once again. However, it is suggested that raspberries and other plants are periodically sampled to ensure that arsenic concentrations remain low. Willow, soapberries, gooseberries, and black currents were also collected from the same locations during the 2001 field season and are in storage at UBC should further analysis be required.

6.1.3 Arctic Gold and Silver Mine Site

Undetectable arsenic concentrations in soapberries collected during the 2001 field season indicate that these berries are safe to eat, and residents can return to this berry-picking site. No conclusions could be made about other species at this mining property, although a full collection of mossberries, Labrador tea, and willow leaves and stems were also sampled during 2001 and are available for analysis if requested.

6.2 Limitations

Several procedural details may explain the presence of unusual data.

In order to mimic consumption habits by wildlife and humans, the forage plants of willow twigs and caribou moss were deliberately not rinsed with water during sample preparation, unlike the medicinal species of Labrador tea and willow leaves. It is noted that the caribou moss may have contained dust particles or small amounts of debris not removed during the cleaning process. Insufficient rinsing of mushroom stalks may have allowed soil particles to remain. As willow leaves and twigs were prepared differently, the ability to directly compare willow parts is affected.

Organic arsenic concentrations in some samples (mostly soils) in this study were unusually high, even exceeding the inorganic concentration in certain cases. Organic arsenic is not common, except in mushrooms, some plants, fish, algae, shellfish, and worms (W. Cullen, pers. comm., 2002). The most plausible explanation is the laboratory technique of subtracting HCl extractable (inorganic) results from the total concentration to determine organic concentration (L. Chan, pers. comm., 2002; W. Cullen, pers. comm., 2002). When inorganic arsenic is bound in a complicated soil matrix (e.g. to organic ligands), it is not easily extracted; consequently the value reported as inorganic arsenic will be lower than the true concentration, and the organic concentration will be falsely elevated (L. Chan, pers. comm., 2002). Another source was critical of this technique, stating that "crude separations into so-called 'organic' and 'inorganic' fractions have been based on methods that have been shown to be applicable to some food, such as fish, but the value of those separations when applied to other foods, such as meat and grain, is moot" (National Research Council, 1999, 67).

Laboratory procedures did not include sieving soil samples prior to analysis. Due to a potential inclusion of humus material, organic matter content was determined in soil samples with detectable organic arsenic using the LOI method. Unfortunately, there was little correlation, suggesting that the inorganic arsenic was bound to compounds other than organic matter (such as the iron and aluminum oxides described earlier).

6.3 Conclusions

Arsenic is a common element found in various environmental media, and is particularly prevalent in certain areas of the Yukon containing arsenic-rich bedrock. Low arsenic concentrations were found in vegetation collected around the Mt. Nansen, Venus, and Arctic Gold and Silver mining properties, and the 2001 data were typical of other Yukon data for the same species. Higher concentrations were found in select samples of caribou moss, willow, and Labrador tea collected from Mt. Nansen. Windborne dust from historic and recent mining activity may be a cause, but natural uptake of soil arsenic is also likely. Most species revealed decreasing concentrations at locations further away from probable point sources of contamination. The majority of this detectable arsenic was inorganic. At sites where data were available in previous years, temporal trends indicate either a decrease in arsenic (after the Venus tailings were capped) or a continuation of non-detectable results (Mt. Nansen). Berries had consistently low or undetectable arsenic concentrations at all three mine sites.

Tolerable Daily Intake data are provided for local residents to make informed choices about where to pick popular plant foods and medicines. More information is required about the uptake of arsenic from vegetation not directly consumed by humans, such as food eaten by animals, or medicinal species.

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Appendices

A1. Nutritional table for important plant foods and medicines used in the Yukon.

A2. Latin, (Northern) Tutchone, Tagish, Tlingit, and common names of some Yukon plant species.

A3a. ANOVA results for testing differences between the means (Wilcoxon Rank Sum test for independent groups at _ = 0.05) for location (1, 2, or 3). Data sets include total arsenic, inorganic arsenic, and organic arsenic.

A3b. Results of normality and significant means tests done after ANOVAs were performed.

A3c. Results of equal variance, and model testing to determine effects of geology on arsenic concentrations at each mine site location (1, 2, or 3).

A3d. Results of statistical tests comparing willow stems versus willow leaves.

A4. Comparison of mean total arsenic concentrations in data collected from previous studies and this study.

A5. Tolerable Daily Intake (TDI) calculations based on the mean, maximum, and minimum (dry and wet) inorganic arsenic concentrations (shown in bold) in different plant samples. Tables are differentiated by species and location (1, 2, or 3).

A6a. Glossary of common plant compounds.

A6b. Glossary of selected terms used in or related to this dissertation.

A1. Nutritional table for important plant foods and medicines used in the Yukon (from Kuhnlein and Turner (1991) unless indicated). Data based on 100 g fresh (wet) weight. Dashes represent unavailable information.

Scientific name	Common name	Part used	Food energy kcal	Water g	Protein g	Fat g	Carbo-. hydrate g	Crude fiber g	Vit. C mg	Vit. A RE	Ca mg	K mg
Vaccinium ovalifolium	oval-leafed blueberry	berry	49	87	1.1	0.5	11.3	3.3	6.2	1	16	-
Vaccinium uliginosum	bog blueberry	berry	45	88	0.7	0.6	10.6	3.3	-	-	19	-
Vaccinium caespitosum	dwarf blueberry	fruit	-	-	-	-	-	-	15	-	-	-
V. vitis-idaea	lowbush cranberries	fruit	62	82	0.7	0.7	14.9	1.4	21.2	-	13	98
Ledum groenlandicum	common Labrador tea	dry leaves	-	42	4.2	0.7	-	-	98.2	-	215	-
L. decumbens	northern Labrador tea	dry leaves	-	47	4.4	-	8.7	-	13.8	-	-	-
Salix arctica	arctic willow	leaves	-	-	6.9	-	-	-	-	-	170	-
S. reticulata	net veined willow	leaves	-	67	3.8	2	25.9	-	-	-	267	-
Salix species	willow	leaves	-	66	5.1	-	28	3.3	41	1830	268	472
Empetrum nigrum	crowberry	fruit	35	89	0.2	0.7	9.5	5.9	51	-	9	87
Shepherdia canadensis	soapberry	fruit	72	81	1.8	0.7	6.6	1.1	-	-	16	-
Rubus arcticus	dwarf raspberry	berry	-	-	-	-	-	-	38.8	11	-	-
Rubus chamaemorus	cloudberry	berry	50	84	2	1	9.6	6	130	-	17	231
Rubus species	raspberry	berry	49	86	0.9	0.6	11.6	3	25	13	22	152
Rubus idaeus	wild raspberry	fruit	65	83	0.6	0.8	15.8	4.5	22.3	13	36	-
Rubus strigosis	wild raspberry	berry	67	79	1.6	1.1	14.6	-	-	-	47	176
Arctostaphylos uva-ursi	bearberry (stoneberry)	berry	92	75	0.7	1.1	22.4	14.8	-	-	37	-
Fragaria species	wild strawberry	fruit	-	89	0.7	0.6	-	2.1	5.9	8	43	164
Ribes hudsonianum	black current	fruit	-	-	-	-	-	-	41	-	-	-
Ribes lacustre	bristly black current	berry	59	86	1.5	2.3	9.7	3.5	58.2	3	68	-
Ribes oxyacanthoides	gooseberry	berry	58	82	1	0.3	14.6	1.9	-	-	91	613
Rosa acicularis	prickly rose (hips)	fruit	55	65	2.4	0.7	21.3	-	1481	263	-	-
Viburnum edule	highbush cranberry	fruit	39	89	0.1	0.4	9.4	3.8	13.4	6	24	-
Ribes triste	red current	fruit	-	-	-	-	-	-	51.5	-	-	-
Arctostaphylos rubra	bearberry (red)	berry	-	85	0.5	-	5.9	-	82.3	-	-	-
Juniperus spp.	juniper	leaves	-	-	12.8	-	-	-	167	-	-	-
Abies balsamea	fir	greens	-	-	8.8	11.9	-	21.7	243	-	75	46
Picea mariana	black spruce	needles	-	49	2.5	-	11.8	-	120	-	-	-
Epilobium angustifolium	fireweed	leaves	-	76	6.5	-	2.9	1.4	88	22	175	404

A1 contd.

Scientific name	Common name	Part used	Food energy kcal	Water g	Protein g	Fat g	Carbo-. hydrate g	Crude fiber g	Vit. C mg	Vit. A RE	Ca mg	K mg
Betula papyrifera	birch	twigs/leaves	-	48	4.9	5.5	-	11.6	-	157	434	-
Betula glandulosa	dwarf birch	leaves	-	58	8.1	-	8.5	-	-	-	-	-
Betula glandulosa	dwarf birch	inner bark	-	43	3.1	-	14	-	11	-	-	-
Hedysarum alpinum	bear root	roots	-	-	-	-	-	-	29	-	-	-
Allium schoenoprasum	wild chives/onions	greens	27	-	2.7	0.6	-	-	32	-	83	-
Alnus crispa	red willow (alder)	bark	270	50	4.3	-	-	-	-	-	-	-
Populus balsamifera	balsam poplar	bark	230	49	1.9	-	-	-	-	-	-	-
Populus tremuloides	trembling aspen	bark	-	41	1.3	-	-	31.7	-	-	684	130
Rumex arcticus	arctic dock	greens	-	90	2.3	0.7	6.5	1.1	-	-	2	-
Taraxacum officinale	dandelion	greens	45	85	2.7	0.7	9.2	1.6	35	1400	209	422
Achillea millefolium	yarrow	leaves	-	79	3.8	-	-	-	-	-	225	645
Morchella species*	morel mushroom	unknown	13	92.6	1.8	0.5	0.4	3.4	1	-	6	320

* from Holland *et al* . (1991)

Species data not available for the following common Yukon plants:

Scientific name	Common name
P. glauca	white spruce
Leccinum spp.	Bolete mushrooms
Cladina/Cetraria species	caribou moss (lichen)
Artemisia tilesii	sage
Polygonum alaskanum	"wild rhubarb"
Lycoperdon	puffballs
Taraxacum	dandelion

A2. Latin, (Northern) Tutchone, Tagish, Tlingit, and common names of some Yukon plant species (from LSCFN, 1999; Thornton, 1999; McClellan, 2001).

Latin	**Aboriginal Tongue**			**English common names**
	(Northern) Tutchone	**Tagish**	**Tlingit**	
Arctostaphylos Uva-Ursi	jik inlän	djl' djE' łoni	t'Inx	bearberry, stoneberry, kinnikinick
Cladina and Cetraria spp.	nįngay			caribou moss, reindeer lichen
Empetrum nigrum	dänt'ró	nEn djl' jUR'	xitłi w As'i	crowberry, mossberry, blackberry
Fragaria glauca	hutsí jík		tłEtk'i	strawberry, spiderberry, groundberry
Juniperus spp.	ts'ek'i jík	tc'ecgE' E dan'EIE	yeł'łEqw' wAs'i	juniper berry, crowberry, crowpaint berry
Leccinum spp.	łųranji, dläknji	dIIRa ji		bolete mushroom, orange top, squirrel grub, squirrel food
Ledum spp.	ts'ago		s'Ixt ciłtin	Labrador tea, Hudson's Bay tea, Trapper's tea, muskeg tea
Lycoperdon spp.	chęghro		xyetł łEq w', ts'AgEx q'awu łeqw'	puffball mushrooms, thunderbird paint, dead people paint
Picea	ts'ok, ts'ok dzí (spruce gum)		'As'gox' (pitch)	spruce
Ribes hudsonianum/ R. lacustre	tlįn jík (black current)			black current, bristly black current
Ribes oxyacanthoides	hághwo jík			gooseberry
Rosa spp.	inchyąw		q'an yeł w As'i	rosehips
Rubus acaulis	dech'ok jík			raspberry, bear kidney, salmon eggs
Rubus chamaemorus	näntlät	cAc tc'Ecl'	t'á qahágu'	salmonberry, cloudberry
Rubus parviflorus			nExw'	thimbleberry
Salix spp.	k'áy		tcatł dai	willow
Shepherdia Canadensis	nįnghrò	cwA x djl'	xÁqł'i wAs'i	soapberry, soopolallie, mooseberry, Canada buffaloberry
Sphagnum	néshémbáy det' aw			peat moss, red moss
Vaccinium spp.	nänddhi	nana' dza	łÁx w łu	blueberry
Vaccinium vitis-idaea	intl'ät		q'Ec qahágu'	lowbush cranberry, lingonberry, mountain cranberry
Viburnum edule	gókhyo		kAx wÉx	highbush cranberry

A3a. ANOVA results for testing differences among locations (1, 2, or 3) at each site (Wilcoxon Rank Sum test for independent groups at _ = 0.05). Data sets include total arsenic, inorganic arsenic, and organic arsenic.

TOTAL ARSENIC

Site	Species	location	Result significant?
Mt. Nansen	blueberry	0.472	no
	caribou moss	0.001	yes
	cranberry	0.214	no
	Labrador tea	0.002	yes
	crowberry	0.241	no
	mushroom	0.034	yes
	willow leaves	0.001	yes
	willow stems	0.000	yes
	soil	0.276	no
AGSM	soapberry	1.000	no
	soil	0.082	no
Venus	raspberry	0.005	yes
	soil	0.027	yes

INORGANIC ARSENIC

Site	Species	location	Result significant?
Mt. Nansen	blueberry	0.472	no
	caribou moss	0.001	yes
	cranberry	0.214	no
	Labrador tea	0.002	yes
	crowberry	0.106	no
	mushroom	0.024	yes
	willow leaves	0.001	yes
	willow stems	0.001	yes
	soil	0.264	no
AGSM	soapberry	1.000	no
	soil	0.035	yes
Venus	raspberry	0.005	yes
	soil	0.027	yes

ORGANIC ARSENIC

Site	Species	location	Result significant?
Mt. Nansen	blueberry	1.000	no
	caribou moss	0.006	yes
	cranberry	1.000	no
	Labrador tea	0.040	yes
	crowberry	0.264	no
	mushroom	0.376	no
	willow leaves	0.092	no
	willow stems	0.054	no
	soil	0.987	no
AGSM	soapberry	1.000	no
	soil	0.503	no
Venus	raspberry	0.368	no
	soil	0.066	no

A3b. Results of normality and significant means tests done after ANOVAs were performed. Data sets include total, inorganic, and organic arsenic. Signicant means determined for location (1, 2, or 3) representing increasing distance from point sources of contamination at the mine site indicated.

*=log(x) transformed data, **=ranked (original) data, ns= not significant (p<0.05), dash "-"=test not applicable

TOTAL	normality test	significant means tests			
Species **Mt. Nansen**	*Shapiro-Wilk* accept if >0.001	*Tukey-Kramer HSD* location: N1, N2, or N3	*Dunnett, Student's t* location	*Dunn* nonparametric data Q.05: 3=2.394, 2=1.960 location	Q
blueberry**	<0.0001	ns	ns	ns	
caribou moss*	0.7748	N1-N3, N2-N3	N1-N2, N1-N3, N2-N3	-	
cranberry**	<0.0001	ns	ns	ns	
Labrador tea*	0.0048	N1-N3, N2-N3	N1-N3, N2-N3	-	
mossberry**	<0.0001	ns	ns	ns	
mushroom**	<0.0001	N2-N3	N2-N3	N2-N3	2.7283
willow leaves**	<0.0008	N1-N2, N1-N3	N1-N2, N1-N3, N2-N3	N1-N2, N1-N3	2.64,3.74
willow stems*	0.0058	N1-N3	N1-N2, N1-N3, N2-N3	-	
soil*	0.1285	ns	ns	-	
AGSM					
soapberry	no value	ns	ns	-	
soil	0.0150	ns	A1 and A3	-	
Venus					
raspberry**	<0.0002	V1-V2, V1-V3	V1-V2, V1-V3	V1-V2, V1-V3	3.03,3.03
soil*	0.0966	V1-V2, V1-V3	V1-V2, V1-V3	-	

INORGANIC	normality test		significant means tests		
Species **Mt. Nansen**	*Shapiro-Wilk* accept if >0.001	*Tukey-Kramer HSD* location: N1, N2, or N3	*Dunnett, Student's t* location	*Dunn* nonparametric data Q.05: 3=2.394, 2=1.960 location	Q
blueberry**	<.0001	ns	ns	ns	
caribou moss*	0.43380	N1-N3, N2-N3	N1-N3, N2-N3	-	
cranberry**	<.0001	ns	ns	ns	
Labrador tea*	0.00130	N1-N3, N2-N3	N1-N3, N2-N3	-	
mossberry**	<.0001	ns	ns	ns	
mushroom**	<.0001	N2-N3	N2-N3	N2-N3	2.8523

A3b contd.

INORGANIC	normality test		significant means tests		
Species **Mt. Nansen**	*Shapiro-Wilk* accept if >0.001	*Tukey-Kramer HSD* location: N1, N2, or N3	*Dunnett, Student's t* location	*Dunn* nonparametric data Q.05: 3=2.394, 2=1.960 location	Q
willow leaves**	0.00030	N1-N2, N1-N3, N2-N3	N1-N2, N1-N3, N2-N3	N1-N2,N1-N3	2.64,3.74
willow stems*	0.00100	N1-N3	N1-N3, N2-N3	-	
soil*	0.19660	ns	ns	-	
AGSM					
soapberry	no value	ns	ns	-	
soil	0.00160	ns	A1-A3, A1-A2	-	
Venus					
raspberry**	0.00010	V1-V2, V1-V3	V1-V2, V1-V3	V1-V2, V1-V3	3.03,3.03
soil*	0.14950	V1-V3	V1-V2, V1-V3	-	

ORGANIC	normality test	significant means tests			
Species **Mt. Nansen**	*Shapiro-Wilk* accept if >0.001	*Tukey-Kramer HSD* location: N1, N2, or N3	*Dunnett, Student's t* location	*Dunn* nonparametric data Q.05: 3=2.394, 2=1.960 location	Q
blueberry**	no value	ns	ns	-	
caribou moss*	0.00660	N1-N3	N1-N3	-	
cranberry**	no value	ns	ns	-	
Labrador tea**	<.0001	N1-N3	N1-N3	ns	
mossberry**	<.0001	ns	ns	ns	
mushroom**	<.0001	ns	ns	ns	
willow leaves**	<.0001	ns	N1-N2 (student's)	ns	
willow stems**	<.0001	N1-N3	N1-N3	ns	
soil*	0.00440	ns	ns	-	
AGSM					
soapberry	no value	ns	ns	-	
soil	0.00140	ns	ns	-	
Venus					
raspberry**	<.0001	ns	ns	ns	
soil*	0.28520	V1-V2, V1-V3	V1-V2, V1-V3	-	

A3c. Results of equal variance, and model testing to determine effects of geology on arsenic concentrations at each mine site location (1, 2, or 3). Data sets include total, inorganic, and organic arsenic.
*=log(x) transformed data, **=ranked (original) data, dash "-"=test not applicable

TOTAL	equal variance test: use Welch if p < 0.05)			model fitting: on logtransformed or normal data					
Species	*ANOVA F test*	*Welch F test*	*O'Brien* test result if applicable	Geology Model Variables		variable significant if p <0.05 Geol KMN	Geol PN1		
Mt. Nansen	location	location		Geology	location	location	location	N1 (A1,V1)	N2 (A2,V2)
blueberry**	0.4951	no value	0.3811	0.5293	0.4787	0.3249	0.6325	0.6097	0.2342
caribou moss*	<0.0001	0.0002		0.3294	0.0006	0.9310	0.3345	0.0025	0.0990
cranberry**	0.2219	no value	0.0816	0.5671	0.2175	0.3574	0.6639	0.4374	0.09
Labrador tea*	<0.0001	0.0115		0.0584	<0.0001	0.2885	0.0352	0.0005	0.0345
mossberry**	0.2519	no value	0.1041	0.2527	0.0085	0.0024	0.0175	0.37	0.2902
mushroom**	0.0231	no value	0.0419	0.007	0.0032	0.0048	0.1358	0.0978	0.0009
willow leaves**	<0.0001	<0.0001		0.5836	0.0047	0.3654	0.6607	0.0014	0.5943
willow stems*	0.0011	0.0021		0.8367	0.0299	0.6643	0.9137	0.0166	0.7216
soil*	0.1645	0.2378		0.7299	0.5896	0.5793	0.9097	0.326	0.9423
AGSM									
soapberry	-1.0000	no value		---	---	---	---	---	---
soil	0.0507	0.1038		---	0.0507			0.0202	0.4524
Venus									
raspberry**	<0.0001	no value	0.1004						
soil*	0.0006	0.0157		---	0.0006			0.0002	0.0861

INORGANIC	equal variance test: use Welch if p < 0.05)			model fitting: on logtransformed or normal data					
Species	*ANOVA F test*	*Welch F test*	*O'Brien* test result if applicable	Geology Model Variables		variable significant if p <0.05 Geol KMN	Geol PN1		
Mt. Nansen	location	location		Geology	location	location	location	N1 (A1,V1)	N2 (A2,V2)
blueberry**	0.4951	no value	0.3811	0.5293	0.4787	0.3249	0.6325	0.6097	0.2342
caribou moss*	<0.0001	0.0001		0.375	0.0011	0.849	0.4915	0.0059	0.079
cranberry**	0.2219	no value	0.0816	0.5671	0.2175	0.3574	0.6639	0.4374	0.09
Labrador tea*	<0.0001	0.0115		0.0268	<0.0001	0.3074	0.0216	0.0004	0.0127
mossberry**	0.1017	no value	0.0111	0.0016	1	0.0012	0.08	1	0.9172
mushroom**	0.0142	no value	0.0732	0.0161	0.0027	0.0105	0.1828	0.0919	0.5991

A3c contd.

INORGANIC	equal variance test: use Welch if p < 0.05)			model fitting: on logtransformed or normal data					
Species	*ANOVA F test*	*Welch F test*	*O'Brien* test result if	Geology Model Variables		variable significant if p <0.05 Geol KMN	Geol PN1		
Mt. Nansen	location	location	applicable	Geology	location	location	location	N1 (A1,V1)	N2 (A2,V2)
willow leaves**	<0.0001	<0.0001		0.4131	0.0018	0.3993	0.9534	0.0007	1
willow stems*	0.0038	0.0069		0.6924	0.0751	0.4987	0.813	0.0505	0.0007
soil*	0.1577	0.2002		0.7111	0.5922	0.5595	0.8986	0.3237	0.9111
AGSM									
soapberry	-1.0000	no value		---	---	---	---	---	
soil	0.0422	0.1326							
Venus									
raspberry**	<0.0001	no value	0.1004						
soil*	0.0091	0.0342							

ORGANIC	equal variance test: use Welch if p < 0.05)			model fitting: on logtransformed or normal data					
Species	*ANOVA F test* on normal, logtransformed, or ranked data	*Welch F test*	*O'Brien* test result if	Geology Model Variables		variable significant if p <0.05 Geol KMN	Geol PN1		
Mt. Nansen	location	location	applicable	Geology	location	location	location	N1 (A1,V1)	N2 (A2,V2)
blueberry**	-1.0000	no value		---	---	---	---	---	
caribou moss*	0.0116	0.0202		0.1128	0.0046	0.2614	0.054	0.0068	0.3479
cranberry**	-1.0000	no value		---	---	---	---	---	
Labrador tea**	0.0306	no value	0.0071	0.9809	0.211	0.8626	0.931	0.1193	0.8966
mossberry**	0.2752	no value	0.2083	0.1501	0.0551	0.3448	0.0792	0.1793	0.1152
mushroom**	0.3943	no value	0.3394	0.05	0.7319	0.0303	0.2703	0.7368	0.4391
willow leaves**	0.0865	no value	0.0194	0.0063	0.0015	0.0271	0.8148	0.0028	0.0017
willow stems**	0.0463	no value	0.0002	0.0004	0.0001	0.0003	0.0441	<.0001	0.0638
soil*	0.9812	0.9789		0.6178	0.8239	0.372	0.6207	0.5408	0.8831
AGSM									
soapberry	-1.0000	no value		---	---	---	---	---	
soil	0.4018	0.2715							
Venus									
raspberry**	0.4053	no value	0.2867						
soil*	0.0241	0.0397							

A3d. Results of statistical tests when comparing willow stems and willow leaves. Data sets include total, inorganic,and organic arsenic. Though not displayed here, all Tukey-Kramer HSD results (testing for significant means) were non-significant

	normality test	equal variance test: use Welch if p < 0.05)		
	Shapiro-Wilk accept if >0.001	*ANOVA F test* site type 1	*Welch F test* site type 1	*O'Brien* test result if applicable
TOTAL				
willow stems and leaves	0.0037 (both)	0.9359	0.9359	
	0.2585 (stems)			
	0.0192 (leaves)			
willows N1	-	0.7723	0.7726	
willows N2	-	0.7865	0.7867	
willows N3	-	0.5435	0.5445	
INORGANIC				
willow stems and leaves	0.0023 (both)	0.9265	0.9265	
	0.007 (leaves)			
	0.249 (stems)			
willows N1	-	1	1	
willows N2	-	0.7586	0.7587	
willows N3	-	0.7352	0.7352	
ORGANIC				
willow stems and leaves	<.0001 (both)	0.9649	0.9649	
	<.0001 (leaves)			
	<.0001 (stems)			
willows N1	-	0.7984	0.7984	
willows N2	-	0.3101	no value	0.0032
willows N3	-	0.0991	no value	0.2925

A4. Comparison of mean total arsenic concentrations in data collected from previous studies and this study. Non-applicability indicated with a dash. Legend for sources: A = Gamberg (2000); B = Godin and Osler (1985); C = this study; D = Roach (1995); E = Roach, pers. comm., 2002; F = Roach and Cunningham (2000).

Plant	Mean Total As (mg/kg)	Location	Year	N	SE	Plant Part	Species	Source
Blueberry	<dl	Ross River	1993	2	0.00	berry	*Vaccinium uliginosum*	A
Blueberry	<dl	Watson Lake	1993	3	0.00	berry	*Vaccinium uliginosum*	A
Blueberry	<dl	Watson Lake	1995	1	-	berry	*Vaccinium uliginosum*	A
Blueberry	<dl	Haines Junction	1995	1	-	berry	*Vaccinium uliginosum*	A
Blueberry	<dl	Whitehorse	1995	3	0.00	berry	*Vaccinium uliginosum*	A
Blueberry	<dl	Mt. Nansen (N2)	1984	1	-	berry	alpine blueberry (*Vaccinium* spp.)	B
Blueberry	0.04	Mt. Nansen (N2)	2001	9	0.06	berry	*Vaccinium* spp.	C
Blueberry	0.09	Mt. Nansen (N1)	2001	7	0.04	berry	*Vaccinium* spp.	C
Blueberry	<dl	Mt. Nansen (N3)	2001	6	0.00	berry	*Vaccinium* spp.	C
Caribou Moss	0.10	Dawson	1993	3	0.01	thallus	*Cladina* sp.	A
Caribou Moss	0.14	Ross River	1993	3	0.01	thallus	*Cladina* sp.	A
Caribou Moss	<dl	Ross River	1994	12	0.00	thallus	*Cladina* sp.	A
Caribou Moss	2.55	Ross River	1994	1	-	thallus	*Cladina* sp.	A
Caribou Moss	31.14	Mt. Nansen (N1)	2001	6	13.86	thallus	*Cladina*/*Cetraria* spp.	C
Caribou Moss	8.87	Mt. Nansen (N2)	2001	9	3.93	thallus	*Cladina*/*Cetraria* spp.	C
Caribou Moss	0.68	Mt. Nansen (N3)	2001	6	0.23	thallus	*Cladina*/*Cetraria* spp.	C
Lowbush cranberry	<dl	Ross River	1993	2	0.00	berry	*Vaccinium vitis-idaea*	A
Lowbush cranberry	<dl	Watson Lake	1993	3	0.00	berry	*Vaccinium vitis-idaea*	A
Lowbush cranberry	<dl	Watson Lake	1995	1	-	berry	*Vaccinium vitis-idaea*	A
Lowbush cranberry	<dl	Haines Junction	1995	1	-	berry	*Vaccinium vitis-idaea*	A
Lowbush cranberry	<dl	Teslin	1995	1	-	berry	*Vaccinium vitis-idaea*	A
Lowbush cranberry	<dl	Whitehorse	1995	2	0.00	berry	*Vaccinium vitis-idaea*	A
Lowbush cranberry	0.04	Mt. Nansen (N1)	2001	8	0.04	berry	*Vaccinium vitis-idaea*	C

A4 contd.

Plant	Mean Total As (mg/kg)	Location	Year	N	SE	Plant Part	Species	Source
Lowbush cranberry	0.15	Mt. Nansen (N2)	2001	9	0.07	berry	*Vaccinium vitis-idaea*	C
Lowbush cranberry	0.00	Mt. Nansen (N3)	2001	6	0.00	berry	*Vaccinium vitis-idaea*	C
Crowberry	<dl	Ross River	1993	1	-	berry	*Empetrum nigrum*	A
Crowberry	<dl	Watson Lake	1993	3	0.00	berry	*Empetrum nigrum*	A
Crowberry	<dl	Watson Lake	1995	1	-	berry	*Empetrum nigrum*	A
Crowberry	<dl	Haines Junction	1995	1	-	berry	*Empetrum nigrum*	A
Crowberry	<dl	Teslin	1995	1	-	berry	*Empetrum nigrum*	A
Crowberry	<dl	Whitehorse	1995	5	0.00	berry	*Empetrum nigrum*	A
Crowberry	0.05	Mt. Nansen (N2)	1984	3	0.00	berry	*Empetrum nigrum*	B
Crowberry	<dl	Mt. Nansen (N2)	1984	3	0.00	berry	*Empetrum nigrum*	B
Crowberry	0.17	Mt. Nansen (N2)	2001	9	0.00	berry	*Empetrum nigrum*	C
Crowberry	0.00	Mt. Nansen (N1)	2001	7	0.11	berry	*Empetrum nigrum*	C
Crowberry	0.07	Mt. Nansen (N3)	2001	6	0.07	berry	*Empetrum nigrum*	C
Labrador Tea	<dl	Ross River	1993	2	0.00	branch	*Ledum groenlandicum*	A
Labrador Tea	<dl	Watson Lake	1993	2	0.00	branch	*Ledum groenlandicum*	A
Labrador Tea	16.67	Mt. Nansen (N1)	2001	6	14.25	branch	*L. groenlandicum/decumbens*	C
Labrador Tea	0.61	Mt. Nansen (N2)	2001	9	0.15	branch	*L. groenlandicum/decumbens*	C
Labrador Tea	0.10	Mt. Nansen (N3)	2001	6	0.07	branch	*L. groenlandicum/decumbens*	C
Mushroom	0.25	Whitehorse	1995	1	-	thallus	not identified	A
Mushroom	0.07	Whitehorse	1995	1	-	thallus	*Leccinum* spp.	A
Mushroom	1.00	Whitehorse	1995	1	-	thallus	not identified	A
Mushroom	0.59	Mt. Nansen (N1)	2001	7	0.29	stem	*Leccinum* spp.	C
Mushroom	5.19	Mt. Nansen (N2)	2001	8	4.24	stem	*Leccinum* spp.	C
Mushroom	0.00	Mt. Nansen (N3)	2001	6	0.00	stem	*Leccinum* spp.	C
Raspberry	15.00	Venus (V1)	1983	1	-	berry	not identified	B
Raspberry	4.70	Venus (V1)	1983	1	-	berry	not identified	B

A4 contd.

Plant	Mean Total As (mg/kg)	Location	Year	N	SE	Plant Part	Species	Source
Raspberry	36.60	Venus (V1)	1984	3	14.24	berry	not identified	B
Raspberry	93.30	Venus (V1)	1984	3	8.82	berry	not identified	B
Raspberry	134.50	Venus (V1)	1995	2	5.50	berry	not identified	D
Raspberry	0.28	Venus (V1)	2001	4	0.58	berry	*Rubus ideaus*	C
Raspberry	0.10	Venus (V1)	2002	1	-	berry	not identified	E
Raspberry	<dl	Venus (V2)	1984	3	0.00	berry	not identified	B
Raspberry	2.40	Venus (V2)	1999	1	-	berry	not identified	F
Raspberry	<dl	Venus (V2)	2001	4	0.00	berry	*Rubus ideaus*	C
Raspberry	<dl	Venus (V3)	2001	4	0.00	berry	*Rubus ideaus*	C
Raspberry	<dl	Ross River	1993	1	-	berry	*Rubus ideaus*	A
Raspberry	<dl	Watson Lake	1993	4	0.00	berry	*Rubus ideaus*	A
Raspberry	<dl	Haines Junction	1995	1	-	berry	*Rubus ideaus*	A
Raspberry	<dl	Teslin	1995	1	-	berry	*Rubus ideaus*	A
Raspberry	<dl	Whitehorse	1995	1	-	berry	*Rubus ideaus*	A
Raspberry	4.60	Arctic Gold & Silver (A2)	1999	I	-	berry	not identified	F
Raspberry	0.20	Arctic Gold & Silver (A3)	1999	I	-	berry	not identified	F
Soapberry	<dl	Ross River	1993	1	-	berry	*Shepherdia canadensis*	A
Soapberry	<dl	Watson Lake	1993	1	-	berry	*Shepherdia canadensis*	A
Soapberry	<dl	Haines Junction	1995	1	-	berry	*Shepherdia canadensis*	A
Soapberry	<dl	Whitehorse	1995	3	0.00	berry	*Shepherdia canadensis*	A
Soapberry	<dl	Arctic Gold & Silver (A1)	2001	4	0.00	berry	*Shepherdia canadensis*	C
Soapberry	<dl	Arctic Gold & Silver (A2)	2001	3	0.00	berry	*Shepherdia canadensis*	C
Soapberry	<dl	Arctic Gold & Silver (A3)	2001	3	0.00	berry	*Shepherdia canadensis*	C
Willow	<dl	Watson Lake	1994	5	0.00	twigs	*Salix longistylus/arbusculoides*	A
Willow	0.23	Watson Lake	1995	5	0.20	twigs	*Salix* spp.	A
Willow	0.03	Watson Lake	1995	4	0.01	twigs	*Salix* spp.	A

A4 contd.

Plant	Mean Total As (mg/kg)	Location	Year	N	SE	Plant Part	Species	Source
Willow	43.90	Arctic Gold & Silver (A1)	1999	1	-	twigs	not identified	F
Willow	2.40	Arctic Gold & Silver (A2)	1999	1	-	twigs	not identified	F
Willow	5.69	Mt. Nansen (N1)	2001	7	3.83	twigs	*Salix* spp.	C
Willow	0.59	Mt. Nansen (N2)	2001	9	0.13	twigs	*Salix* spp.	C
Willow	0.08	Mt. Nansen (N3)	2001	6	0.03	twigs	*Salix* spp.	C
Willow	4.19	Mt. Nansen (N1)	2001	7	2.99	leaves	*Salix* spp.	C
Willow	0.30	Mt. Nansen (N2)	2001	9	0.09	leaves	*Salix* spp.	C
Willow	0.07	Mt. Nansen (N3)	2001	6	0.04	leaves	*Salix* spp.	C
Soil	80.00	Mt. Nansen (N2) surface	1984	2	n/a		-	B
Soil	60.00	Mt. Nansen (N2) depth	1984	2	n/a		-	B
Soil	70.00	Mt. Nansen (N2) surface	1984	2	n/a		-	B
Soil	30.00	Mt. Nansen (N2) depth	1984	2	n/a		-	B
Soil	43.71	Mt. Nansen (N2)	2001	9	15.54		-	C
Soil	714.93	Mt. Nansen (N1)	2001	8	439.87		-	C
Soil	22.80	Mt. Nansen (N3)	2001	6	11.86		-	C
Soil	45000.00	Venus (V1) surface	1984	2	n/a		-	B
Soil	800.00	Venus (V1) depth	1984	2	n/a		-	B
Soil	83000.00	Venus (V1) surface	1984	2	n/a		-	B
Soil	70000.00	Venus (V1) depth	1984	2	n/a		-	B
Soil	11373.00	Venus (V1)	2001	3	6701.70		-	C
Soil	75.83	Venus (Venus (V2))	2001	3	27.21		-	C
Soil	12.10	Venus (V3)	2001	3	0.32		-	C
Soil	62.03	Arctic Gold & Silver (A1)	2001	4	17.18		-	C
Soil	22.33	Arctic Gold & Silver (A2)	2001	3	8.81		-	C
Soil	9.07	Arctic Gold & Silver (A3)	2001	3	1.89		-	C

A5. Tolerable Daily Intake (TDI) calculations based on the mean, maximum, and minimum (dry weight and wet weight) inorganic arsenic concentrations (shown in bold) in different plant samples. Tables are differentiated by species and location (1, 2, or 3); absence of a location indicates concentrations were undetectable (age and body weight classes from Health Canada (1996)).

Mt. Nansen property:

Labrador Tea: Location 1

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) **2.097**	Mean (dry) **7.033**	Max. (wet) **9.78**	Max. (dry) **32.1**	Min. (wet) **0.1**	Min. (dry) **0.4**
0 to <6 months	7	6.7	2.0	1.4	0.4	140.0	35.0
6 months to <5 years	13	12.4	3.7	2.7	0.8	260.0	65.0
5 to <12 years	27	25.8	7.7	5.5	1.7	540.0	135.0
12 to <20 years	57	54.4	16.2	11.7	3.6	1140.0	285.0
20+ years	70	66.8	19.9	14.3	4.4	1400.0	350.0

Labrador Tea: Location 2

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.160	Mean (dry) 0.500	Max. (wet) 0.42	Max. (dry) 1.2	Min. (wet) 0.06	Min. (dry) 0.2
0 to <6 months	7	87.5	28.0	33.3	11.7	1458.3	140.0
6 months to <5 years	13	162.5	52.0	61.9	21.7	2708.3	260.0
5 to <12 years	27	337.5	108.0	128.6	45.0	5625.0	540.0
12 to <20 years	57	712.5	228.0	271.4	95.0	11875.0	1140.0
20+ years	70	875.0	280.0	333.3	116.7	14583.3	1400.0

Labrador tea: Location 3

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.037	Mean (dry) 0.101	Max. (wet) 0.15	Max. (dry) 0.4	Min. (wet) < DL	Min. (dry) <DL
0 to <6 months	7	375.0	139.1	93.3	35.0	N/A	N/A
6 months to <5 years	13	696.4	258.3	173.3	65.0	N/A	N/A
5 to <12 years	27	1446.4	536.4	360.0	135.0	N/A	N/A
12 to <20 years	57	3053.6	1132.5	760.0	285.0	N/A	N/A
20+ years	70	3750.0	1390.7	933.3	350.0	N/A	N/A

Willow leaves: Location 1

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.987	Mean (dry) 4.043	Max. (wet) 5.26	Max. (dry) 22.1	Min. (wet) 0.12	Min. (dry) 0.4
0 to <6 months	7	14.2	3.5	2.7	0.6	116.7	35.0
6 months to <5 years	13	26.3	6.4	4.9	1.2	216.7	65.0
5 to <12 years	27	54.7	13.4	10.3	2.4	450.0	135.0
12 to <20 years	57	115.5	28.2	21.7	5.2	950.0	285.0
20+ years	70	141.8	34.6	26.6	6.3	1166.7	350.0

Willow leaves: Location 2

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.071	Mean (dry) 0.3	Max. (wet) 0.14	Max. (dry) 0.7	Min. (wet) < DL	Min. (dry) <DL
0 to <6 months	7	197.2	46.7	100.0	20.0	N/A	N/A
6 months to <5 years	13	366.2	86.7	185.7	37.1	N/A	N/A
5 to <12 years	27	760.6	180.0	385.7	77.1	N/A	N/A
12 to <20 years	57	1605.6	380.0	814.3	162.9	N/A	N/A
20+ years	70	1971.8	466.7	1000.0	200.0	N/A	N/A

Willow leaves: Location 3

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.011	Mean (dry) 0.034	Max. (wet) 0.06	Max. (dry) 0.2	Min. (wet) < DL	Min. (dry) <DL
0 to <6 months	7	1272.7	411.8	233.3	70.0	N/A	N/A
6 months to <5 years	13	2363.6	764.7	433.3	130.0	N/A	N/A
5 to <12 years	27	4909.1	1588.2	900.0	270.0	N/A	N/A
12 to <20 years	57	10363.6	3352.9	1900.0	570.0	N/A	N/A
20+ years	70	12727.3	4117.6	2333.3	700.0	N/A	N/A

Mushroom: Location 1.

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.055	Mean (dry) 0.458	Max. (wet) 0.19	Max. (dry) 1.4	Min. (wet) < DL	Min. (dry) <DL
0 to <6 months	7	254.5	30.6	73.7	10.0	N/A	N/A
6 months to <5 years	13	472.7	56.8	136.8	18.6	N/A	N/A
5 to <12 years	27	981.8	117.9	284.2	38.6	N/A	N/A
12 to <20 years	57	2072.7	248.9	600.0	81.4	N/A	N/A
20+ years	70	2545.5	305.7	736.8	100.0	N/A	N/A

Mushroom: Location 2.

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.532	Mean (dry) 5.125	Max. (wet) 3.69	Max. (dry) 34.8	Min. (wet) < DL	Min. (dry) <DL
0 to <6 months	7	26.3	2.7	3.8	0.4	N/A	N/A
6 months to <5 years	13	48.9	5.1	7.0	0.7	N/A	N/A
5 to <12 years	27	101.5	10.5	14.6	1.6	N/A	N/A
12 to <20 years	57	214.3	22.2	30.9	3.3	N/A	N/A
20+ years	70	263.2	27.3	37.9	4.0	N/A	N/A

Venus Mine tailings site:

Raspberries: Location 1

Age	Body weight (kg)	TDI (g/d)					
		Mean (wet) 0.17	Mean (dry) 0.775	Max. (wet) 0.25	Max. (dry) 1.2	Min. (wet) 0.11	Min. (dry) 0.4
0 to <6 months	7	81.2	18.1	56.0	11.7	127.3	35.0
6 months to <5 years	13	150.7	33.5	104.0	21.7	236.4	65.0
5 to <12 years	27	313.0	69.7	216.0	45.0	490.9	135.0
12 to <20 years	57	660.9	147.1	456.0	95.0	1036.4	285.0
20+ years	70	811.6	180.6	560.0	116.7	1272.7	350.0

A6a. Glossary of common plant compounds (from Marles et al. (2000))

alkaloid – bitter tasting compounds produced naturally by plants and used for herbivore defense (affects their nervous system)

flavonoid – important antioxidant

iridoid – deters herbivores and helps prevent bacterial infections

salicylate – type of compound from which acetylesalicyclic acid (ASA or aspirin) was originally synthesized. Relieves pain, reduces fever, and acts as an anti-inflammatory.

saponin – chemical that acts like detergent, which froths if shaken in water.

tannin – acts as an astringent (causing tissue to shrink and fluids to be retained); is effective at stopping bleeding and preventing infection when applied topically to cuts and sores. Ingesting large doses (e.g. strong tea) is damaging to the throat lining.

volatile/essential oil – aromatic oils with medicinal, industrial, and cosmetic uses (e.g. components of cleaning supplies and aromatherapy). They evaporate easily.

A6b. Glossary of selected terms used in or related to this dissertation

bioaccumulation – ability of living organisms to accumulate elements in concentrations higher than the median for the species in an unpolluted environment (Wittig, 1993)

cation exchange capacity (CEC) – the ability of a soil to hold and exchange ions; organic matter and clays are good ion exchangers as negative charges on soil colloids attract cations (Fergusson, 1990)

contaminant – a substance whose presence causes a deviation from the normal composition of the environment (Environmental Sciences Group, 1995)

ligand – a substance that binds with another, such as an organic molecule with a metal (Ripley *et al.*, 1996)

metalloids/semi-metal – elements that exhibit only a partial metallic character or they occur in metallic as well as non-metallic form (Streit and Stumm, 1993)

phytotoxicity - toxic to plants (Ripley *et al.*, 1996)

pollutant – a substance that has a detrimental effect on the environment (Environmental Sciences Group, 1995)

reclamation – an approximation of pre-disturbance conditions with an emphasis on the re-establishment of native species. Generally includes any treatment that is not restoration, where pre-mining conditions need not be restored but rather where a different condition is established that is appropriate to surrounding land uses and conditions (Bowman and Baker, 1998)

rehabilitation – the return of a disturbed site to a stable and permanent use or condition that is directed by a pre-mine plan. The use or condition must not contribute to environmental deterioration and be consistent with surrounding aesthetic values (Bowman and Baker, 1998)

restoration – affected landscapes are restored to conditions that existed prior to the disturbance in question. This includes recreating the original topography and re-establishing the previous land use or land condition, as well as groundwater patterns and plant and animal communities (Bowman and Baker, 1998)

tailings – component of washed or milled ore that is too poor to be treated further; as distinguished from the concentrates – the "materials of value" (Ripley *et al.*, 1996)

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